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The attached document entitled "Investigation of the Potential Use of Alcohol Fuels As Components of Transportation Fuel Supply" was prepared as the result of a consultant study commissioned by the Energy Planning Directorate of Transport Canada.

This report represents the third in a series of studies on alternative fuels; the two previous ones related to propane and compressed natural gas.

Readers are encouraged to respond to this report. Comments would be appreciated and should be directed to Ian Gilbert, Senior Advisor, Energy Planning, at the above address or by telephone to (613) 996-9731.

Attach.

Le document ci-joint intitulé "Investigation of the Potential Use of Alcohol Fuels as Components of Transportation Fuel Supply" a été préparé à la suite d'une étude consultative commissionnée par la direction générale de la Planification de l'énergie de Transports Canada.

Ce rapport représent la troisième dans une série des études des carburants alternatif; les deux précédentes se préoccupaient du gaz propane et du gaz naturel comprimé.

Nous encourageons les lecteurs à répondre à ce rapport. Tout commentaire sera apprécié et devrait être envoyé à M. Ian Gilbert dont l'adresse est ci-haut mentionnée ou en le rejoignant au (613) 996-9731.

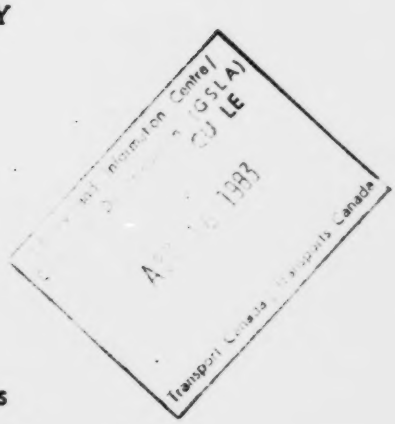
P.j.

La direction de la
Planification de l'énergie

Energy Planning Directorate

Canada

INVESTIGATION OF THE POTENTIAL USE OF ALCOHOL FUELS AS COMPONENTS OF TRANSPORTATION FUEL SUPPLY



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DISCLAIMER

The contents of this report reflect the views of the participating contractors and are not necessarily the official views or policies of any Department or Agency of the Canadian Government.

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1. RÉSUMÉ ET CONCLUSIONS

La présente étude traite des possibilités commerciales des alcools comme carburants automobiles jusqu'en 1995. Essentiellement, trois facteurs détermineront l'étendue de ces possibilités et le moment de leur mise en application: l'avancement de la technique, le respect des règlements et des exigences, et les avantages économiques des alcools sur les carburants conventionnels. L'importance de chaque facteur varie selon le type d'alcool (méthanol ou éthanol), sa concentration (mélangé ou pur) et le type de moteur envisagé (à allumage par étincelle ou par compression).

Selon l'étude, le méthanol, pur ou mélangé, devrait coûter moins cher que l'éthanol. Les véhicules idéaux sont les automobiles et les camionnettes à allumage par étincelle. Voici quatre solutions sur la pénétration du marché (deux pour le méthanol pur et deux pour les mélanges). En ce qui a trait aux mélanges, il en faudra ainsi de 580 à 2375 millions de litres en 1995, ce qui représente de 30 à 125 pourcent de la capacité de production excédentaire aux besoins du pays. Pour ce qui est du méthanol pur, la première solution rend le méthanol trop cher par rapport à l'essence. Si les taxes fédérale et provinciale sont exclues, une demande de 577 millions de litres de méthanol est prévue pour 1995, soit 30 pourcent de la capacité de production excédentaire. Dans l'autre solution où le méthanol est simplement en concurrence avec l'essence, on prévoit une demande de 379,2 millions de litres en 1995. Si les taxes fédérale et provinciale sont exclues, la demande passerait à 1137,0 millions de litres, soit 60 pourcent de la capacité de production excédentaire.

Le méthanol est préférable à cause de son coût

Les règlements et les exigences techniques sur le méthanol et l'éthanol seront généralement semblables. Cependant, le méthanol devrait coûter beaucoup moins cher que l'éthanol.

Le méthanol aura beaucoup plus de difficulté que l'éthanol à répondre aux exigences techniques, que ce soit dans un mélange ou à l'état pur. L'objectif est de produire des mélanges d'éthanol ou de méthanol comparables à l'essence sans plomb. Ces mélanges conviendraient alors aux moteurs à essence, qu'il suffirait de régler en conséquence. Pour brûler un alcool pur, un moteur doit être optimisé et ses dispositifs connexes doivent tirer parti des nombreuses propriétés physiques, chimiques et thermiques avantageuses de ce carburant. À certains points de vue, les alcools purs sont meilleurs que l'essence.

Les règlements et les exigences des autres partis concernés seront essentiellement identiques pour l'éthanol et le méthanol. Comme le méthanol est plus toxique, les exigences régissant sa manutention devront être plus sévères. Les deux liquides présentent un danger, car ils sont inflammables;

ils ne devraient cependant pas causer plus de problèmes que l'essence. Il faudra régler certains points, comme la qualité du carburant et ses spécifications, la sécurité des véhicules, les normes sur la pollution et la politique de taxation.

L'éthanol est fortement désavantagé par rapport au méthanol du point de vue des coûts de production. Les coûts de production actuels (teneur énergétique équivalente) du méthanol dérivé du gaz naturel sont à peu près les mêmes que ceux de l'essence sans plomb. L'éthanol extrait de diverses matières premières coûte de deux à trois fois plus cher que le méthanol extrait des installations actuelles. À moins que le coût des matières premières baisse ou en raison de progrès technologiques, l'éthanol ne servira probablement pas de carburant automobile à l'échelle nationale. Il pourrait servir sur les marchés locaux, si une matière première peu coûteuse autrement inutilisable ou excédentaire est disponible (à une coopérative agricole, par exemple).

Le méthanol a le grand avantage d'être facilement disponible. L'industrie a pris une expansion rapide au cours des dernières années. Sa capacité de production atteint maintenant environ 1,5 million de tonnes par année, en excédent des besoins du marché intérieur traditionnel. Selon certains, cet excédent pourrait constituer une source immédiate de méthanol pour les marchés intérieurs dans le secteur des transports. L'apparition d'un excédent de méthanol sur les marchés a rendu les prix flexibles et entraîné la concurrence dans un marché d'exportation traditionnellement sûr. Par conséquent, les divers producteurs évaluent sérieusement les possibilités du méthanol dans le secteur des transports.

Le marché du méthanol devrait viser les véhicules à allumage par étincelle plutôt que ceux à allumage par compression. Bien que plusieurs solutions intéressantes existent à propos de ces derniers, presque toutes en sont aux premières phases de leur développement et très peu ont été mises à l'essai en Amérique du Nord. On comprend mieux les exigences techniques sur l'emploi d'alcools dans les moteurs à allumage par étincelle. Ces derniers sont d'ailleurs les plus nombreux, ce qui permettra de mieux supplanter les carburants conventionnels. Étant donné ces considérations et les tendances prévues quant aux véhicules, les automobiles et les camionnettes constituent le marché le plus intéressant, à court et à moyen termes, pour les alcools.

Des mélanges de méthanol pourraient être disponibles en 1985

Grâce à un effort concerté, les mélanges à faible teneur en méthanol (5 à 10%) pourraient être disponibles commercialement sur les marchés nationaux en 1985 et ceux à forte teneur (15%) en 1990 ou avant. Les prix prévus devraient intéresser les raffineries qui recherchent des additifs pouvant hausser l'indice d'octane, entre autres options. Au détail, le prix d'un mélange méthanol-essence sera égal ou légèrement inférieur à celui de l'essence sans plomb.

La pénétration qu'a connu l'essence sans plomb permet de mesurer la demande éventuelle pour le mélange de méthanol. Bien que l'implantation de l'essence sans plomb ait été obligatoire et que celle du méthanol ne tienne qu'à sa rentabilité, son arrivée indique que l'infrastructure en place est capable de fournir rapidement un carburant automobile nouveau, mais similaire. Pour obtenir une plage de prédictions, on suppose deux niveaux de pénétration: le niveau haut, identique à celui de l'essence sans plomb, et le niveau bas, qui représente la moitié du précédent.

Si le niveau est haut, la demande en méthanol devrait être de 2375 millions de litres en 1995, soit 125 pourcent de la capacité de production excédentaire aux besoins actuels des marchés industriels intérieurs. Le manque de cosolvants sera le facteur limitatif. Pour répondre à la demande prévue de mélange de méthanol, il faudra environ 792 millions de litres de cosolvant, alors que sa disponibilité atteint seulement 110 millions de litres. À ce niveau de pénétration, le marché de consommation (automobiles et camionnettes) sera presque saturé en 1995.

Si le niveau est bas, la demande en méthanol devrait être de 580 millions de litres en 1995, soit 31 pourcent de la capacité de production. Le manque de cosolvants demeurera un facteur limitatif, bien qu'il ne soit plus que de 80 millions de litres (comparativement à 682 millions de litres dans la solution précédente).

Le méthanol pur ne sera vraisemblablement pas disponible avant 1990

Pour assurer une utilisation répandue du méthanol pur dans les automobiles, il faudra consacrer beaucoup plus d'efforts que pour les mélanges de méthanol. À l'échelle nationale, il ne sera pas disponible commercialement avant 1990. Avant même qu'il soit disponible, ses spécifications devront être établies, les voies de mise en marché et de distribution choisies, et les règlements révisés. Il sera techniquement facile de construire des moteurs optimisés pour fonctionner au méthanol pur, mais on devra effectuer de longs essais avant de les offrir au grand public.

Comme le moteur des véhicules devra être optimisé, seule une fraction des vénicules neufs en sera munie. L'historique des ventes de camions moyens à moteur diesel permet d'évaluer combien de véhicules à moteur au méthanol pur seront vendus, si ce carburant est moins cher que l'essence. Le taux de pénétration augmente ou diminue, selon l'importance de cette différence de prix.

Deux solutions sont évaluées quant aux prix, l'une incluant les taxes fédérale et provinciale sur le carburant, l'autre les excluant. La solution type suppose que le prix du pétrole brut demeure stable après 1985. L'autre suppose que ce prix augmente de 2 pourcent par année après 1985 et que le prix du méthanol demeure stable comme dans la solution type. Ce prix pourrait demeurer stable si le marché est flexible ou si un escompte est accordé du fait qu'il s'agit d'un carburant nouveau.

Dans la solution type, le méthanol ne pourra pénétrer le marché que s'il n'est pas sujet aux taxes fédérale et provinciale; autrement, il coûtera un peu plus cher que l'essence jusqu'en 1995.

En l'absence de taxes, le méthanol coûtera moins cher que l'essence: 23 pourcent en 1990, puis 18 pourcent en 1995; la période d'amortissement est de 1,7 et 2,3 ans respectivement, à supposer que les véhicules modifiés coûtent en moyenne 250 $ de plus. Ainsi, on prévoit que 296 540 véhicules au méthanol circuleront en 1995, nécessitant 577,1 millions de litres de carburant. Cela représente 1,8 pourcent du parc des automobiles et des camionnettes et 30 pourcent de la capacité de production excédentaire actuelle.

Dans l'autre solution, le méthanol sera meilleur marché que l'essence, que les taxes soient imposées (10% moins cher) ou non (30% moins cher). L'offre d'un escompte par les producteurs et la hausse du prix de l'essence feront que 194 830 véhicules au méthanol circuleront en 1995, nécessitant 379,2 millions de litres de carburant. Si aucune taxe n'est imposée, il y aura alors 584 250 véhicules, qui consommeront 1370,0 millions de litres. Ainsi, respectivement 1,2 et 3,6 pourcent des véhicules du parc rouleront au méthanol pur, nécessitant 20 et 60 pourcent de la capacité de production disponible.

L'usage commercial de mélanges à faible teneur en méthanol en 1985 et de méthanol pur en 1990 exigera un effort concerté et coordonné de la part du gouvernement, des fournisseurs de méthanol et de l'industrie automobile. Il sera très important de définir les spécifications du carburant, de répondre aux exigences en matière d'essais des véhicules et de démontrer la compatibilité de l'infrastructure.

Que le méthanol utilisé soit pur ou mélangé, l'essai des véhicules et l'établissement des spécifications doivent s'effectuer en parallèle. Ces spécifications sont nécessaires pour uniformiser la qualité du carburant et réduire au minimum les risques de mauvaise performance des véhicules. Des essais contrôlés permettront de déterminer que le carburant convient à une variété de conditions d'utilisation.

Mélanges à faible teneur (M5): spécifier la teneur en cosolvant nécessaire pour inhiber la séparation des phases et définir les limites acceptables de tension de vapeur. Si les véhicules d'essai donnent des résultats positifs, on devra procéder à des essais commerciaux, à divers points de vente au détail, avant de lancer la production en série des véhicules. Les fournisseurs et les distributeurs de méthanol devront faire preuve de collaboration.

Les essais et les exigences pour les spécifications des mélanges à forte teneur (M10-15) seront semblables. Entre autres recherches supplémentaires à effectuer sur les spécifications: établir si un traitement aux additifs anti-usure est nécessaire. Il faut aussi établir la compatibilité des éléments du moteur et du circuit d'alimentation.

Pour ce qui est du méthanol pur, il faut donner une grande priorité à la recherche sur les spécifications. Parmi les exigences: établissement des méthodes d'essai, ajustement du degré de vaporisation, limitation de la pollution par évaporation, protection contre les tampons de vapeur, type et importance des autres traitements par additifs nécessaires pour améliorer la performance et la longévité. La performance optimale dépend de la combinaison des spécifications du carburant et des modifications du moteur. On devra effectuer des essais contrôlés sur des véhicules de plusieurs constructeurs, dans divers climats.

La pénétration des carburants au méthanol sera facilitée si l'on utilise le plus possible la présente infrastructure de transport et de distribution. Il reste à prouver que le méthanol (pur et mélangé) convient aux nombreux éléments de cette infrastructure, notamment les pipelines, les citernes et les pompes des stations-service. Beaucoup de ces travaux de recherche peuvent être menés dans le cadre du programme d'essai des véhicules au niveau commercial.

Bien que la recherche porte surtout sur le marché des véhicules à essence, il serait bon d'étudier également le marché des véhicules diesel. Le remplacement du carburant diesel par du méthanol dans les moteurs à allumage par compression est beaucoup moins avancé que le remplacement de l'essence. En plus des transporteurs routiers qui utilisent le diesel, les transporteurs maritimes et ferroviaires pourraient constituer un marché intéressant pour le méthanol.

1. SUMMARY AND CONCLUSIONS

This study assesses the commercial prospects for alcohols as components of the national transportation fuel supply for over-the-road vehicles to the year 1995. The timing and extent of alcohol fuel prospects will be primarily determined by three factors: technical readiness; institutional and regulatory compliance; and utilization economics of alcohols relative to conventional fuels. The significance of each factor varies by the type of alcohol (methanol or ethanol) considered, the nature of its application (blend or neat) and the vehicle engine technology (spark ignition or compression ignition) required.

The results of the study indicate that neat methanol and methanol blends are more attractive than ethanol, on the basis of expected prices. The ideal target markets are spark ignition engines in passenger automobiles and light duty trucks. Two penetration scenarios are evaluated for each of methanol blends and neat methanol. For methanol blends, between 580 and 2,375 Ml will be required in 1995, depending on the scenario. Penetration at these levels would require between 30 and 125 percent of currently available production capacity which is surplus to domestic requirements. Two scenarios are also evaluated for neat methanol. In the base case scenario, methanol is uncompetitive with gasoline on its own economic merits. If federal and provincial fuel taxes are not assessed, a methanol demand of 577 Ml in 1995 is projected or 30 percent of surplus production capacity. In an alternate pricing scenario, a demand of 379.2 Ml of methanol in 1995 is forecast with methanol competing with gasoline on its own merits. If federal and provincial fuel taxes are not assessed, demand will be 1,137.0 Ml or 60 percent of currently surplus production capacity.

Methanol is Favoured On The Basis of Price

The technical and regulatory requirements of both methanol and ethanol will generally be similar. Methanol is expected to be available at prices substantially less than ethanol however.

The technical requirements will be somewhat more challenging for methanol than for ethanol, both for blends and as a neat fuel. The objective for blend fuels, whether ethanol or methanol is to produce a fuel having specifications similar to existing unleaded gasoline. Such blended fuels will be broadly compatible with existing spark ignition engines, with relatively minor engine adjustment. The utilization of neat alcohols will require optimized engine and vehicle systems to take advantage of several favourable physical, chemical and thermal properties of the alcohols. In some respects, neat alcohols are better fuels than conventional gasoline.

Institutional and regulatory requirements will also be essentially similar for ethanol and methanol. Somewhat more stringent handling requirements will be necessary for methanol, to reflect its greater toxicity. Methanol and ethanol are

flammable liquids and will have safety hazards associated with their use; but relative to gasoline, they are likely to be acceptable and containable problems. Issues which must be addressed include: fuel quality and specifications, vehicle safety, emissions standards specific to alcohol fuels and taxation policy.

On the basis of expected production costs, ethanol is significantly less attractive than methanol. Current production costs (equivalent energy content) of methanol derived from natural gas are roughly the same as unleaded gasoline. Ethanol, as produced from various feedstocks are two to three times more expensive than methanol from existing production facilities. In the absence of significant cost reductions in feedstocks or as a result of technology advances, ethanol is an unlikely candidate for national transportation markets. Local markets might be served where a ready source of low cost surplus or waste feedstocks are available, at a farm co-operative, for example.

A significant advantage for methanol is its availability. The industry has expanded rapidly over the last several years, and currently has roughly 1.5 million tonnes per year production capacity, surplus to the tranditional domestic market requirements. It has been suggested that this surplus capacity could be a ready source of methanol fuel supply for domestic transportation markets. An emerging surplus of methanol on global markets has created soft prices and competitive pressures on traditionally secure export markets. This, in turn, is prompting the various producers to seriously assess the transportation sector as a new market for methanol.

Vehicles utilizing spark ignition engines are considered to be more attractive methanol target markets than compression ignition engines. While there are several promising approaches for utilizing alcohols in compression ignition engines, most are at an early stage of development and few have been tested in North America. The technical requirements for utilizing alcohols as a fuel in spark ignition engines are more clearly understood. Spark ignition engines also represent a substantially greater proportion of the vehicle market, thereby permitting greater potential displacement of conventional fuels. Based on these considerations, in combination with expected vehicle trends, automobiles and light duty trucks are the most attractive short to medium term market candidates for alcohol fuels.

Methanol Blends Could be Available in 1985

With a concerted effort, methanol blends could be commercially available to national markets by 1985 for low level blends (5-10 percent) and 1990 or earlier for higher level blends (15 percent). Projected methanol prices should be attractive to refineries seeking octane enhancing additives, relative to several other options. Methanol/gasoline blends are projected to have pump prices similar or perhaps slightly lower than conventionally produced unleaded gasoline.

The historical penetration of unleaded gasoline is used to provide a measure of potential methanol blend demand. Although the introduction of unleaded

gasoline was mandatory, while methanol blend penetration will stand on its economic merits, its introduction does indicate the capacity of the existing infrastructure to quickly introduce a new but similar fuel into the transportation market. To give a range of outcomes, two penetration rates are assessed: high penetration parallels the historical experience of unleaded gasoline; and low penetration which is half the observed rate of unleaded gasoline.

Under the high penetration case, methanol demand in 1995 is projected to be 2,375 Ml or 125 percent of the 1,900 Ml of production capacity currently surplus to existing domestic industrial markets. Co-solvent availability will be a limiting factor. To satisfy the projected methanol blend demand, roughly 792 Ml of co-solvent will be required, compared to an estimated current availability of 110 Ml. At this level of demand, the automobile and light duty truck consuming markets will be approaching saturation in 1995.

For the low penetration case, methanol demand in 1995 is forecast to be 580 Ml or 31 percent of present day surplus capacity. Co-solvent availability will still be a limiting factor, but less pronounced with a shortfall of 80 Ml compared to 682 Ml in the high penetration scenario.

Neat Methanol is Unlikely to be Available before 1990

Neat methanol will require a more substantial level of effort than methanol blends to achieve widespread introduction into vehicle markets. It is unlikely to be commercially available to national markets before 1990. Fuel specification procedures, marketing and distribution channels selection, and regulatory reviews will be required in advance of commercial availability. Engines optimized for neat methanol will not be technically difficult to produce, but will have a lengthy testing process leading to commercial scale production.

As factory optimized vehicles are required, neat methanol penetration will be restricted to a portion of new vehicle sales. Historical diesel sales in the medium duty truck market are used to estimate that portion of the new vehicle market which are likely neat methanol conversion opportunities where methanol prices are more attractive than gasoline. The rate of penetration is adjusted up or down depending on the methanol price advantage over gasoline.

Two scenarios based on different pricing assumptions are evaluated, with and without the imposition of federal and provincial fuel taxes. The base case scenario assumes no real growth in crude oil prices, past 1985. An alternate scenario, assumes an annual 2 percent real growth rate in oil prices past 1985 and methanol prices held constant at the same level as the base case. Constant methanol prices may occur if export markets remain soft or as a price discount to an emerging new transportation fuel market.

In the base case scenario, methanol penetration will only occur in the case where federal and provincial fuel taxes are not assessed. Where taxes are assessed, there is a slight pricing disadvantage for methanol relative to gasoline by 1995.

Without taxes, the methanol price advantage over gasoline varies from 23 percent in 1990 to 18 percent in 1995 with payback periods of 1.7 and 2.3 years respectively, for an average incremental vehicle cost of $250. At this price advantage, 296,540 methanol vehicles are forecast to be in service in 1995, with fuel requirements of 577.1 Ml of methanol. This level of penetration is equivalent to 1.8 percent of the forecast automobile and light truck vehicle population and 30 percent of currently available surplus production capacity.

In the alternate scenario, methanol will have a price advantage over gasoline for both taxation scenarios: an average of 10 percent in the full taxation case; and 30 percent where fuel taxes are not assessed. Price discounting by producers, in combination with rising gasoline prices results in 194,830 methanol vehicles by 1995 with a fuel demand of 379.2 Ml of methanol. If further incentives are available by not assessing fuel taxes, 584,250 methanol vehicles are projected, requiring 1,370.0 Ml of methanol. At these levels of methanol penetration, 1.2 and 3.6 percent of vehicles will be powered by neat methanol, for each taxation case respectively, requiring 20 and 60 percent of available production capacity.

The commercial utilization of low level methanol blends by 1985 and neat methanol by 1990 will require a concerted and co-ordinated effort by government, methanol suppliers, fuel distributors and the automotive industry. Of particular importance will be the definition of fuel specifications, completion of vehicle test requirements and demonstration of infrastructure compatibility.

Whether methanol is used neat or as a blend, vehicle testing and fuel specification activities should occur in tandem. Fuel specification is required to ensure consistent fuel quality and minimize the potential for unacceptable vehicle performance. Controlled vehicle tests will demonstrate the practicability of utilizing the fuel for a range of driving conditions.

For low level blends (M5) the type and amount of co-solvent required to inhibit phase separation should be specified and acceptable vapour pressure limits defined. If positive results are achieved by current vehicle tests, commercial level testing through a number of retail outlets will be required in advance of full scale introduction. The co-operation of methanol suppliers and fuel distributors will be required.

The vehicle testing and fuel specification requirements for high level blends (M10-15) will be similar to low level blends. Additional specifications related research include establishing the need for anti-wear additive treatment. Materials compatibility of engine and fuel system components must be established.

For neat methanol, fuel specification related research requires high priority. Requirements include establishing testing procedures, how to tailor front end volatility, evaporative emission control, vapour lock protection and the type and quantity of other additive treatments required to enhance performance and durability. Optimum performance will rely on a combination of fuel specification and engine modifications. A controlled vehicle test program using a variety of vehicle makes under varying climatic conditions will be required.

The penetration of methanol fuels will be facilitated by using existing transportation and distribution infrastructure wherever possible. The compatibility of neat or blend methanol fuels to several components of this infrastructure requires demonstration; particularly pipeline distribution, tank storage and dispensing. Much of this research may be conducted in concert with the commercial level vehicle testing program.

While the research emphasis is on gasoline engine vehicle market segments, an extension of the research effort into diesel vehicle markets is warranted. The experience record of substituting methanol for diesel fuel in compression ignition engines is not well developed compared to spark ignition engines. Marine and rail markets, in addition to over the road diesels, may be attractive methanol fuel markets.

2. INTRODUCTION

The National Energy Program (NEP) has plaed a substantial emphasis on reducing the importance of oil in the transportation sector over the remainder of this decade. Federal initiatives are to first halt and subsequently reverse the growth in demand for oil products by this sector. This may be accomplished by conservation, improved engine efficiency and replacement of oil products by alternative fuels. The federal government has established alternative fuel programs which offer taxable grants for those vehicle owners wishing to convert from gasoline to propane or compressed natural gas.

Among the liquid fuel alternatives, methanol and ethanol are receiving widespread interest, both in Canada and abroad, as attractive fuel options capable of extending supplies of petroleum based fuels and which may, under the right conditions, ultimately replace them. These fuels may be used neat in optimized high compression ratio spark ignition engines or as blends in existing engines. Several less developed approaches also allow their utilization in compression ignition engines.

In 1981, the transportation sector consumed 421,952 TJ of energy. As indicated below, over-the-road vehicles accounted for 77 percent of the total consumption, while rail, air and marine accounted for 5 percent, 7 percent and 11 percent respectively.

	1981 Energy Consumption by Sector (TJ)
Rail	21,161
Air	29,740
Marine	44,806
Road Transportation	60,248
Retail Pump	265,997
Total:	421,952

This study focusses on the short to medium term alcohol fuel market potential of the large over-the-road vehicle sector. Ultimately, the rail, air and marine modes may be attractive market candidates for alcohol fuels, but the techncial research record is not as complete at present as for road vehicles. Specific opportunities will include medium speed diesels in marine and rail applications and light aircraft utilizing spark ignition engines.

For over-the-road vehicles, this study assesses:

- technical readiness to utilize alcohol fuels in Chapter 3.
- institutional and regulatory compliance issues in Chapter 4.
- alcohol fuel market economics in Chapter 5.
- alcohol fuel market potential 1995 in Chapter 6.

3. TECHNICAL UTILIZATION REQUIREMENTS

There are several utilization strategies for alcohols as transportation fuel. In spark ignition engines, they may be combusted as neat fuels or as blends with gasoline. In compression ignition engines, they may be used in a variety of ways depending on the type of engine technology considered. In some of these applications, few technical engine-related issues remain to be resolved before widespread commercialization proceeds. In other applications, the research and experimental research has not advanced to the point that commercial prospects can be judged as imminent. The introduction of new fuels, which require significant adjustments to existing engine technology must be preceded by testing to ensure that consumers are not faced with unexpected technical problems.

This section will review the research record and further research requirements for the various applications of alcohol fuels. Primary focus will be on spark ignition and compression ignition engines with a short discussion on other emerging prospects. The practicability, limitations and advantages of alcohol fuels used in dual-fuel systems, retrofitted vehicles and optimized, factory produced vehicles will also be discussed.

3.1 SPARK IGNITION ENGINES

The simplest approach to utilize fuel alcohols in spark ignition engines is to blend moderate amounts of anhydrous alcohol with gasoline. Most of the physical and chemical properties of gasoline, upon which current engine and vehicle design is based, will still be predominant. Relatively minor engine adjustment is usually adequate to secure satisfactory operation. Some of the properties of the blend fuel will be significantly different from unblended gasoline even at relatively low alcohol levels.

A more technically challenging option is to use neat alcohols. In this case, the physical and chemical properties of the alcohols render simple engine calibration adjustments inadequate to secure smooth, efficient and reliable operation. More substantive engine/vehicle redesign is called for under this utilization option.

Table 3.1 lists key physical, chemical and thermal properties of methanol, ethanol, and gasoline. Their effects are reviewed below.

3.1.1 Alcohol fuel advantages

Many of the differences noted in Table 3.1 offer advantages to the utilization of alcohols as a transportation fuel. There is well documented consensus on these advantages. In combination, the utilization of neat alcohols results in increased thermal efficiency, increased power output and greater fuel economy when measured in Km/GJ compared to utilizing gasoline.

TABLE 3.1

SELECTED PROPERTIES OF ALCOHOLS AND GASOLINE

	Gasoline	Methanol	Ethanol
Physical Properties			
Specific Gravity	0.72 - 0.78	0.796	0.794
Vapour Pressure, (Kpa @ 20°)	27.6 - 55.1	13.1	5.5
Boiling Point (°C)	26.7 - 226.7	65	78
Freezing Point (°C)	-56	-97	-114
Viscosity @ 37°C	0.37	0.47	0.85
Energy Density (MJ/L)	32.17	15.77	21.09
Chemical Properties			
Formula	$C_4 - C_{12}$	CH_3OH	C_2H_5OH
Molecular Weight	Varies	32.0	46.1
% Carbon	85 - 88	37.5	52.1
% Hydrogen	12 - 15	12.6	13.1
% Oxygen	0	49.9	34.7
Stoichiometric Air/Fuel Ratio	14.2 - 15.1	6.4	9.0
Thermal Properties			
Lower Heating Value (KJ/Kg)	9052 (avg)	4119	5508
Heat of Vapourization (KJ/Kg)	71.8	242.4	189.7
Octane Ratings:			
Research	91 - 105	106 - 108	106 - 108
Pump	87 - 92	99 - 101	98 - 101
Flammability Limits (% by volume in air)	1.4 - 7.6	6.7 - 36	4.3 - 19
Exothermic Heat of Combustion (MJ/Kg)	43.5	19.6	26.9
Auto ignition Temp. (°C)	232 - 482	470	363
Flash Point (°C)	-45	11	13

Thermal efficiency

The anti-knock (octane) ratings of methanol and ethanol are essentially equal and considerably higher than those of current, commercially available gasolines. Higher compression ratio engines, which demand a higher octane fuel are more efficient than engines which require a lower compression ratio. The result of this improved efficiency is greater fuel economy. Leaner operation with alcohol blends also results in further improvement of efficiency and fuel economy. Cooler combustion reduces heat losses relative to gasoline combustion and also results in a small improvement in engine efficiency. The combined effect of these factors is a typical increase in engine thermal efficiency of about ten percent for neat methanol.

Power output (Ref. 2, 6, 12, 13, 14, 15)

Lower-order alcohols such as methanol and ethanol have a considerably lower energy content than petroleum hydrocarbons on both a mass and a volume basis. To obtain equal engine output, it is necessary to meter the alcohol in significantly larger quantities than required for gasoline. Gasoline has about 2.05 times the energy content of methanol per unit volume, for example, which suggests that the fuel economy with methanol would be about half that with gasoline in kilometers per litre terms. Equal volumes of stoichiometric alcohol-air mixtures and stoichiometric gasoline-air mixture have closely similar energy contents, however. Since piston engines induct fuel-air mixture on a volume basis, engine power output should not change significantly if nothing were changed but the fuel.

Certain properties of the alcohols make engine design changes feasible which yield an appreciably more powerful engine. These properties include: high latent heats of evaporation; high octane values permit increases in compression ratio and/or spark advance; more favourable molar expansion yields more expansion work per unit of intake charge.

In combination, these factors allow the design of smaller engines in place of a larger one at constant performance.

Fuel energy economy (Ref. 1, 4, 8, 10, 11, 16, 17)

Neat alcohols demonstrate greater fuel energy economy (Km per GJ) than hydrocarbon fuels. On a volumetric basis they are penalized due to their lower energy density.

Alcohol-gasoline blends yield lower fuel economy than gasoline, although the loss is not always identical to the size of the fuel energy decrement. For 10 percent methanol and ethanol blends, losses of 2 to 5 percent in fuel economy are typical, based on extensive dynamometer and fleet test analysis in the United States. Heavier vehicles may show smaller losses or even very small gains of fuel economy on blend fuels.

3.1.2 Outstanding Alcohol Fuel Issues

There are two principal outstanding issues in the utilization of alcohol fuels in spark ignition engines:

- driveability - the responsiveness of a vehicle to throttle inputs from the driver.

- materials compatibility - the suitability of traditional metallic and non-metallic materials in fuel distribution storage and dispensing element of the vehicle system.

Although these issues are generally well understood there is, to date, no consensus on their resolution.

Driveability (Ref. 1, 3, 5, 7, 15, 18, 19, 20)

Driveability problems are most pronounced when the engine is cold and while it is warming up. The most severe driveability problem of neat alcohols is the lowest ambient temperature at which an engine can be started. For neat methanol, this is about 10°C. Below this temperature, methanol cannot vapourize sufficiently to form a flammable air-vapour mixture. For neat ethanol, the limit is somewhat higher, about 15°C. Gasoline can volatize sufficiently at temperatures as low as -6°C to permit an engine to start.

The cold start and warm-up volatility limitations of neat alcohols may be overcome by adding relatively small amounts (5 volume percent) of light hydrocarbons or larger amounts (10-15 volume percent) of whole gasoline. This approach is substantially less effective for ethanol than with methanol. An alternative is to incorporate a separate fuel storage system to be used for cold starting.

Driveability may also suffer under high temperature conditions. Hot driveability problems are the result of fuel volatility effects. High temperatures, both ambient and underhood, can cause fuel vapourization in components upstream of the intake manifold (or intake ports) which interferes with the delivery and metering of fuel to the engine. Such conditions are broadly referred to as "vapour lock". Vapour lock occurs with gasolines, but alcohol-gasoline blends exhibit a marked tendency towards this problem. Neat alcohol fuels are much less susceptible to vapour lock than blend fuels. Addition of only 1 to 3 volume percent alcohol to gasoline raises vapour pressure substantially. Methanol's effect in this regard is about three times greater than ethanol's. Fleet tests of ethanol-gasoline blends have produced a mixed data base on this problem; in some cases vapour lock was non-existent, in others, vapour lock was evident.

A driveability penalty associated with some vehicles operating on alcohol fuel blends is related to the leaning effect of the air/fuel ratio: (A/F). Newer vehicles with feedback fuel metering systems are relatively insensitive to this

effect since they maintain constant fuel/air stoichiometry. Preliminary evidence suggests, however, that driveability deteriorates slightly when a three-way catalyst vehicle is operated on alcohol blends. It is unclear whether this is a fuel volatility effect or due to changes in the output of the oxygen sensor which controls the fuel feedback network. Older vehicles vary in their tolerance of alcohol-gasoline blends. Most vehicles built in the last ten years can generally tolerate a 10 percent ethanol blend without significant loss of driveability. Methanol's stronger blend leaning effect limits it to lower concentrations in gasoline blends unless the fuel metering system is adjusted and/or recalibrated.

Materials compatibility (Ref. 21, 22, 23, 24)

Materials compatibility is among the most pervasive and challenging problems posed by the utilization of alcohol fuels. Numerous chemical and physical properties of the alcohols, whether neat or in blends with gasoline, are sufficiently different from those of straight petroleum fuels to cause problems with many materials commonly used in existing systems.

- the solvency of the alcohols for the types of deposits which exist in gasoline distribution and vehicle systems can lead to dirt loosening and plugging of fuel filters, although the problem diminishes as petroleum deposits are dissolved by continued use.

- neat and alcohol blends promote greater metal-to-metal wear than straight gasoline. Ethanol blends tend to be poorer lubricants for metal parts than methanol blends. Neat ethanol, however, seems less prone than neat methanol in promoting metal-to-metal wear.

- since alcohols are much better electrical conductors than gasoline, they are considerably more aggressive as a galvanic corrosion media. Standard corrosion inhibitors which are effective in gasoline have been found, in some cases, to increase fuel system metal corrosion.

- methanol fuels of all types are extremely aggressive toward magnesium and also aluminum, if they contain dissolved or separated water.

- ethanol fuels are less aggressive towards metals. Ethanol will attack magnesium, but more slowly than methanol. Ethanol-gasoline blends, whether phase-separated or not, tend to cause pitting of several metals.

- alcohol fuels also display varying degrees of aggressiveness toward non-metals such as polyamide fuel filter housings. Methanol blends are more aggressive to elastomeric materials than ethanol.

- Severe engine wear has been observed from neat alcohol fuels, particularly in low temperature duty cycles. Cylinder bore wear is especially severe. There are preliminary indications that severe engine wear for neat methanol is engine specific and may not be a general problem.

3.1.3 Research Requirements

The research community is generally very familiar with the advantages and disadvantages of using alcohols as neat or blended fuels. In most cases, a number of specific response options have been identified to alleviate the problems associated with alcohol fuels. In many instances, further research is required and extensive testing remains to be performed. This is especially the case for neat alcohol fuels.

Low level blends

Alcohol/gasoline blends in the order of 10 to 15 percent or less ethanol or 5 percent or less methanol have characteristics which are essentially similar to gasoline. Few issues remain which require significant level of research.

Fuel specification for these blends focus on ensuring consistent fuel quality and performance levels comparable to gasoline. This can normally be accomplished by adjusting the fuel specifications of the base gasoline. Except for the addition of co-solvents in methanol blends, experience indicates no further additives are required. The addition of alcohol to gasoline has a marked effect on volatility and hence on evaporative emissions. Some relatively minor adjustment to current specifications may be necessary.

The utilization of low level blends in existing engines should pose few problems. With the exception of minor materials compatibility problems and effects on engine durability there are no other outstanding issues. These potential issues are unlikely to be significant. Controlled fleet demonstrations are required to ensure these potential issues are properly understood and, if required, responses implemented.

Higher level blends

In contrast to low level blends, blends in excess of 10-15 percent methanol and 25 percent ethanol depart from the characteristics of gasoline in significant ways. There is general concensus that these blends will be more difficult to introduce then the lower level blends.

There are no consensus specifications for these blend levels. While the objective of setting specifications is the same as low level blends (i.e. consistent quality and performance), higher level blends are more susceptible to phase separation and degradation of metal and non-metal materials common to current engine and vehicle configurations. A variety of additives to enhance cold start, and inhibit materials degradation and phase separation need to be selected and tested for performance. There is no consensus on amounts or composition to date.

The most pressing of the vehicle utilization issues relates to materials compatibility for metal and elastomers commonly used in current vehicle and engine systems. In general, methanol will be the more difficult to introduce. Engine wear may be pronounced and the long-term durability of engines has not been

demonstrated. Cold start, warm up and hot driveability remain unresolved but are generally understood. Many of these utilization issues will be resolved by developing appropriate specifications, although some materials substitution in engine and fuel distribution systems may be required.

Neat alcohols

There are few areas involving neat alcohols (including additives and cold start enhancers) which do not require substantial levels of effort to accomplish widespread introduction. The utilization experience of neat alcohols in North America is extremely limited. While the general research requirements and outstanding issues are essentially similar for both methanol and ethanol, there is general consensus that the introduction of methanol will be significantly more problematic. If the more stringent conditions of neat methanol introduction can be met, it would appear that neat ethanol would pose no additional significant problems. The discussion is, therefore, heavily oriented towards methanol.

Specifications related research must have a high priority in any attempt to accelerate the introduction of neat methanol. The lack of a broad based historical testing record leaves all specifications issues without an established means of resolution. Existing gasoline specification and testing procedures will be only of limited use in guiding the development of a consensus position, as the characteristics of neat alcohols are substantially different from conventional hydrocarbon fuels. Little consensus has been reached on what and how much hydrocarbon additives will be used to tailor front end volatility. Seasonal volatility adjustment, evaporative emissions control and vapour lock protection must also be addressed. In addition, seasonal adjustment of volatility may have some impact on octane rating as additions of volatile, lower octane hydrocarbons fluctuate. Requirements for additive treatment to enhance engine performance and durability are generally appreciated but not understood enough to form a consensus position. Cold start, warm up and hot driveability issues remain and additive packages for odourants, flame colourants and anti-corrosion treatment, among others, are still under development.

There is a growing but still incomplete knowledge on the utilization of neat alcohol in spark ignition engines. Materials compatibility for both metals and elastomers and excessive engine wear are known to be significant issues. Driveability, particularly for cold start-up, warming up and hot operation are also known to be issues which require resolution. In some cases, the development of neat alcohol fuel specification and additive packages will resolve issues, in other cases, the development of optimized engines which take maximum advantage of the favourable combustion characteristics of neat alcohol and counteract their unfavourable physical and chemical characteristics will be required. A test program under a variety of climates (i.e. hot, cold, wet) using a variety of vehicle makes will be required before full scale commercial utilization is feasible.

3.2 COMPRESSION IGNITION ENGINES

There are many more basic changes that can be made to diesel engines than spark ignition engines due to the variability of compression-ignition engine systems. Most of the numerous approaches are still at a very early stage of development and few have been tested in North America. Only a few of the options allow utilization of essentially neat alcohols, for most only a limited percentage of alcohol can be introduced. The most promising options are discussed below.

Solutions (Ref. 29, 39, 40, 41, 42, 46)

The easiest method by which alcohols can be used in diesel engines is in the form of solutions. This approach is limited to anhydrous ethanol because methanol is not soluble in the vast majority of diesel fuels. Ethanol itself has limited solubility in diesel fuel and thus ethanol-diesel fuels solutions are restricted to small percentages (typically 20 percent or less) of ethanol. Solubility is also temperature-dependent and very dependent on the water content of the ethanol-diesel fuel blend. The quantity of water that can be tolerated will depend on the minimum ambient temperature to be encountered and the percentage of ethanol in the blend. Due to the hygroscopic nature of ethanol, the water content of ethanol-diesel fuel blends tends to increase gradually during storage. This places a practical limit on ethanol blend percentages to lower values than might otherwise be predicted from experiment.

An advantage of ethanol-diesel fuel solutions is that relatively few major component changes are required for their use. Small adjustments to injection timing and fuel volume delivery may be necessary to restore full power. These adjustments depend on the ethanol concentration and combustion effects of the ethanol.

Emulsions (Ref. 26, 29, 30, 37, 50)

Alcohol-diesel fuel emulsions share many of the advantages and characteristics of ethanol-diesel fuel solutions. The main differences are that an emulsifier is required and that either ethanol or methanol can be used. The emulsifiers generally extend the water tolerance of alcohol-diesel fuel blends relative to solutions without emulsifiers. The major drawbacks are the cost of emulsifiers and their poor low ambient temperature physical properties. Roughly equal amounts of emulsifier and alcohol are needed to create stable emulsions.

Emulsions of alcohols and diesel fuels can be of two basic types; stable and unstable. Stable emulsions are usually micro-emulsions and do not separate under normal ambient conditions. Unstable emulsions tend to separate when left unagitated for a period of time. Stable emulsions are readily handled by typical diesel engine fuel pumps and fuel injection systems. Unstable emulsions pose operational problems as fuel lines and injection lines must be cleared to prevent emulsion separation after the engine is stopped. Starting with a separated emulsion can result in misfire, knock, and possibly engine damage.

Several attempts have been made to form unstabilized diesel fuel-alcohol (and diesel-fuel water) emulsions in-line; that is, at the engine just upstream of the injection pump or injectors. One of the more recent of these was undertaken at the Ontario Research Foundation. A passive, fluid shear creates an emulsion which appears to survive without separating long enough to be injected into the engine cylinders. Few changes need to be made to the engine to accommodate the alcohol. Injection volume and timing may require adjustment to ensure full power and smooth combustion. If straight diesel fuel is subsequently used, over-fueling will occur.

Fumigation (Ref. 31, 36, 44, 48, 49)

Fumigation is a method by which alcohol is introduced into the engine by carbureting or vaporizing the alcohol into the intake air. This requires addition of a carburetor or vapourizer along with a separate fuel tank, lines and controls. In the mid-load range, up to 50 percent of the fuel energy can be derived from the alcohol. The control requirements increase the complexity of the engine control system. Its advantage is the ability to switch readily from fumigation to straight diesel fuel operation.

Dual injection (Ref. 28, 33, 34, 38, 45, 47)

Dual injection is a method by which alcohol is directly injected into the cylinder, and ignited by a pilot charge of diesel fuel. The pilot charge must precede the injection of alcohol, with the two coordinated so that smooth and efficient combustion takes place. Injection of the alcohol before the pilot injection has time to initiate combustion can lead to misfire due to the flame quenching effect of the high latent heats of the alcohols. The amount of diesel fuel required is only that necessary to initiate combustion. This results in nearly 90 percent displacement of diesel fuel by alcohol, under ideal conditions. Increased power output may be possible due to an extended smoke limit.

Disadvantages of dual injection include the complexity and expense of a second injection system, and a second fuel tank and system. Fuel injection pumps and injectors to handle neat alcohols have not been developed.

Spark ignition/spark assist (Ref. 25, 32, 35)

Spark ignition of neat alcohols in diesels provides a way of displacing 100 percent of the diesel fuel normally required. The injection system can be retained as is, but a spark plug must be introduced into the combustion chamber, and the associated ignition system components must be added to the engine. This approach is attractive as it uses the high latent heat of vapourization of the alcohols and their high octane numbers to good advantage. The high compression ratio and positive ignition with resulting smooth combustion lead to very good thermal efficiencies.

Increase alcohol cetane (Ref. 27, 42)

Increasing alcohol cetane numbers is another method of using neat alcohols in diesel engines. Ignition-improving additives are introduced to ensure that compression ignition will occur. This saves the expense and complexity of engine component changes, but the quantity of ignition improvers required (10-20 percent), and their cost currently prohibit their use in most cases. Most of the effective ignition improvers are nitrogen-based compounds, which can aggravate exhaust emission of NO_x. Isoamyl nitrate, TEGDN (triethylene glycol dinitrate) and Kerobrisol BRA have been identified as good methanol ignition improvers. This approach is best suited to areas of lenient exhaust emissions standards where a large number of diesel engines in the field must be converted to use neat alcohol.

Diesels operating directly on cetane-enhanced alcohol need few changes to the vehicle or engine. Injection volume and timing may need adjustment to obtain optimum performance. Since the injection pump must be capable of supplying the total fuel requirements of the engine, its output is usually insufficient to obtain full power and torque. A larger pump, lines and injectors will be necessary to satisfy the fuel injection requirements under these circumstances.

3.3 OTHER ENGINE TECHNOLOGIES

Alternatives to the spark ignition and diesel engines which may be commercialized in the next 20 years, include the direct injection stratified charge (DISC) engine, the Brayton (gas turbine) and Stirling engines. The gas turbine and Stirling engines have an inherent fuel tolerance that exceeds that of today's engine types. The consensus in the oil and automobile industries is that the Stirling engine's chances for commercialization in this century are slight. The gas turbine will likely be limited to special applications such as heavy-duty line-haul trucks and high-priced specialty cars.

The remaining alternative, the DISC engine, received a setback when Ford shelved plans to market its PROCO (Programmed Combustion) engine, a sophisticated, electronically controlled DISC concept. In the U.S., United Parcel Service (UPS) is now the only proponent of DISC engine application. That firm intends to modify some of its existing SI engines for operation as DISC powerplants on the model of the Texaco Controlled Combustion System, one of the earliest DISC concepts.

Most DISC engines have no critical fuel cetane or octane requirement, so the high octane ratings of the alcohols are of no particular value and their low cetane ratings are no particular impediment. The response of the DISC engine to alcohol fuels would not be substantially different from that of the SI engine. The materials compatibility issues would be virtually identical for those components and systems outside the engine (i.e. the fuel tank, fuel lines, fuel pump, etc.) Within the engine, the close-tolerance, high pressure fuel injectors will suffer from the lack of lubricity inherent in neat alcohols and, to a lesser extent, in

alcohol-gasoline blends. The addition of a lubricant additive can overcome these problems.

Unburned fuel (UBF) emissions from the DISC engine tend to be higher than from homogenous charge SI engines. For alcohol fuels, higher emissions of unburned alcohol and possibly of aldehydes are likely. Any DISC engine, operating on hydrocarbons or oxygenate fuels will require catalytic exhaust gas after-treatment to meet current emission standards.

Becuse the DISC engine is quality-governed like a diesel (air-fuel ratio modulation is used for load and speed control rather than air or mixture throttling), its exhaust gas temperature is lower than a comparable quantity-governed (throttled) SI engine. As a result, exhaust catalysts can be considerably less effective, since they may operate below their minimum temperature for chemial activity. This will be especially noticeable at low loads and speeds. Under some circumstances, it may produce aldehydes from unburned alcohol.

3.4 ENGINE/VEHICLE OPTIONS

The market penetration of alcohol fuels will be in part influenced by the number of vehicles which may utilize the fuel. For low level blends, the indication is that existing vehicles will require only modest engine adjustment. Neat fuels, however, require substantial changes to currently available spark ignition engines. Options available to secure as large a portion of this vehicle market as possible are to develop dual fuel systems, retrofit existing vehicles or to mass produce Original Equipment Manufacturer (OEM) optimized vehicles. Other alternative fuels, such as propane and compressed natural gas have taken advantage of the first two options to establish a market presence. In the case of neat alcohol fuels, however, it appears that the only practicable approach will be to produce a factory optimized vehicle.

3.4.1 Dual-fuel systems (Ref. 3, 16, 51)

Little serious attention has been given to the dual-fuel (gasoline or alcohol) concept. For low-level blends, vehicle/engine modification is not necessary. Virtually all vehicles can be thought of as inherently dual-fuel vehicles with respect to gasoline and low-level alcohol/gasoline blends. Low-level alcohol blend fuels which have been commercialized in the U.S. have been expressly formulated to require no engine/vehicle adjustment or modification and to be below the oxygen content (blend leaning effect) which will occasion driveability problems in the existing vehicle fleet.

A dual-fuel vehicle cannot be built to take optimum advantage of neat alcohols' octane ratings. Dual fuel vehicles would require compression ratios much higher than can be tolerated by commercially available gasolines. The complexity of the requisite control scheme, the on-board fuel storage system, and the differing requirements on parts of the two fuel systems make the system impractical.

For some alcohol-fuelled diesel engine options, there are not as many disadvantages to dual-fuel systems as for spark ignition engines. Some diesel engine conversions are by nature dual-fuel arrangements, such as those relying on pilot ignition. Alcohol-fuelled diesel engines are even more experimental than alcohol-fuelled SI engines, however. Were an engine manufacturer to consider producing a diesel engine for use with alcohol, he might well avoid dual-fuel arrangements to obviate the complications of dual-fuel tanks, fuel feed systems, injectors, etc.

Dual-fuel systems are, by their nature, less practical and less likely to be an important avenue by which significant volumes of alcohol fuels enter the commercial marketplace than other approaches. Apart from the slight operational flexibility a dual-fuel vehicle offers, it has few advantages. On the other hand, numerous technical limitations reduce its attractiveness. Compared to dual-fuel vehicles which can operate on gasoline and either LPG or natural gas, gasoline/alcohol vehicles do not represent a proven, commercialized technology with a number of credible, established equipment manufacturers.

3.4.2 Retrofitted vehicles (Ref. 52, 53)

Vehicles retrofitted for alcohol fuel operation have, until comparatively recently, been the mainstays of fleet demonstration programs in the U.S. Typically, such vehicles have been regular production (gasoline) vehicles modified by small specialty shops to be compatible with neat alcohol fuels. Retrofit hardware is available to convert engines to operate on neat alcohols. The success of such tests has demonstrated the feasibility of using alcohol fuels and has in turn encouraged the interest of engine manufacturers. In virtually every case, however, there have been problems which developed in service, indicating that no vehicle retrofit to date has anticipated all problems or been the beneficiary of the extensive preproduction testing routinely imposed on vehicles and components manufactured by major OEMs. The technical sophistication of retrofits varies from do-it-yourself conversions to after market-supplied hardware from established and reputable firms. The overall performance of any retrofit application is a function of the quality of engineering embodied in the hardware.

The issue of quality is paramount and it is apparent that very little hardware on the market today can meet the exacting technical requirements necessary for satisfactory performance. It is clear that retrofitting is the only means of encouraging neat alcohol use in vehicles not factory-optimized to these fuels. It is highly likely, however, that retrofit "kits" will have to be tailored for each vehicle application and possibly for each vehicle model. It is not practical or possible to engineer retrofit hardware which is universally applicable to all vehicles. Unless retrofit kits are very carefully engineered, this option will be at best undesirable and at worst dangerous. Regardless of quality, however, vehicles retrofitted for neat alcohols will void OEM warranties. Vehicle manufacturers are at present not likely to warrant vehicles utilizing any fuel other than that for which they were designed. Driveability, emissions and

materials compatibility problems are not necessarily resolved by hardware currently available. This points to a clear requirement to develop standards for retrofit hardware. Although many reputable suppliers are investigating opportunities for wider utilization, there is, to date, only one recognized supplier in the United States which offers long-term experience and well-engineered hardware, but not for all vehicle models nor to replace every item that might need to be changed. The likelihood of retrofitted vehicles being used in fleet tests and demonstrations over the next several yars is relatively high. Vehicle retrofit has the advantage of allowing tests and demonstrations to be started early, rather than waiting for more OEM interest to develop.

The effect of retrofit on OEM warranties and the lack of comparable hardware warranties by retrofit companies in combination with the consumer's reliance on the craftsmanship, integrity, and expertise of individual shops, retrofit is not likely to support the large-scale (national, provincial, or regional) introduction of alcohol-fueled vehicles.

Typical retrofit costs for neat alcohol operation have been of the order of $1,000-$1,500 (U.S.) per vehicle for significant projects to date. This reflects the inability of small independent shops to realize (or offer) economies of mass production.

3.4.3 Factory-optimized engine/vehicle configurations (Ref. 53, 54)

From the perspective of a vehicle operator, the most desirable approach may be the purchase of neat alcohol vehicles, optimized in design and construction, from an established, major vehicle manufacturer. Single source responsibility for equipment warranty, replacement and spare parts, vehicle service and technical counsel is thus maintained. Extensive pre-production testing, beyond the technical and economic capabilities of independent vehicle modification shops will be afforded. This is the operator's best assurance that technical problems will not surface during operation for which solutions must be improvised by service personnel who may not be intimately familiar with the vehicles and/or components involved.

The practicality of this option is presently limited by the fact that only Ford Motor Company has announced its willingness and intent to manufacture vehicles optimized for neat alcohol fuel service, for demonstration applications. Volkswagen of America has provided about forty vehicles for the early phases of the California Energy Commission fleet demonstration.

The Brazilian experience strongly indicates that optimized vehicles from major manufacturers are the best means of placing large numbers of alcohol-fueled vehicles in the hands of the general public (as distinct from commercial or government fleet owners/operators). In Brazil, the very uneven quality of retrofits proved to be a conspicuous embarrassment for the alcohol fuels program not withstanding the fact that factory-optimized vehicles performed well and reliably. The new vehicle production capacity of the major manufacturers is also in their favour, since retrofit shops typically are small, dealing in tens, rather than thousands or tens of thousands of vehicles.

In the case of U.S. manufacturers, optimized vehicles have been made available for price premiums in the $1,000-$2,000 range (over the price of the comparable gasoline vehicle). Mass production obviously would reduce this differential, as would the entry of other manufacturers into this field. Optimized vehicles produced to date have tended to be somewhat "upscale" regarding options and appointments. A serviceable optimized vehicle could probably be produced today for perhaps as little as $750 to $1,000 above the price of its gasoline counterpart if a minimal level of optional and minimal luxury were specified. Given mass production, price differentials will probably be no more than $500 and perhaps as low as $100.

4. INSTITUTIONAL AND REGULATORY ENVIRONMENT

Alcohols have a long history of production and use in Canada. Methanol, for example, is used as an industrial feedstock in the manufacturing of formaldehyde and polyester fibres. Ethanol is used in the production of medicines and cosmetics in addition to its more familiar use as an alcoholic beverage. In these applications, the production, transportation and distribution of methanol and ethanol are subject to regulations imposed by federal and provincial governments. Experience with alcohol fuels, however, is currently too limited to have led to widespread institutional or regulatory policies.

Alcohol fuels are substantially different from gasoline or diesel. Their physical, chemical and thermal properties suggest a number of areas which will require an institutional or regulatory response. Two broad categories are evident.

- transportation and distribution - which recognize special handling and safety requirements due to toxic effects and fire and explosion hazards.

- utilization of alcohol fuels - which anticipates such issues as safety standards, vehicle insurance and warranties, fuel quality, compliance with emission standards, fuel efficiency standards and taxation.

Representatives of provincial and federal governments were contacted and their views on these potential issues solicited. While few steps have been initiated to address these potential issues, most of those contacted felt that responses could be readily forthcoming. There is a considerable lack of knowledge about alcohols as potential components of the transportation fuel supply and uncertainty on the need to address problems in advance of the commercial availability of alcohol fuels.

4.1 TRANSPORTATION AND DISTRIBUTION

The bulk movement of alcohols from the producer will be similar regardless of whether its transport is for current applications or as transportation fuels. Areas of specific regulatory interest are toxic hazard and fire and explosion hazards.

4.1.1 Alcohol properties

The principal areas of concern in the distribution of alcohols are hazards related to their toxicity and the possibility of fire and explosions. Alcohols will generally have unfavourable effects in these two categories, but relative to gasoline, they will likely be acceptable.

Toxic hazards of the alcohols include ecological disturbances from large spills and low level chronic leakage and physiological hazards to those handling the fuels or who are otherwise exposed to them.

Relatively little work has been performed to characterize the environmental hazards associated with small or large scale spills of methanol or ethanol. In high concentrations, methanol is toxic to most plants, animals and aquatic organisms. In lower concentrations, the effects will be organism specific. The Environmental Emergency Branch of Environment Canada has placed methanol in the top ten priority substances of their hazardous material spill program. Ethanol is considered less hazardous and is found in the top one hundred and fifty list.

The immediate and direct toxicity of alcohols to humans is perhaps the most crucial aspect of the environmental health and safety issues surrounding their introduction as fuels. These effects emphasize the need for careful handling, particularly in the case of methanol.

- methanol is a physiological poison to several systems of the body and can enter the body through direct ingestion, inhalation of vapours or absorption through the skin. Secondary metabolites include formaldehyde and formic acid. Both are physiological poisons. Ingestion of 30 to 60 ml can cause death.

- ethanol is far less toxic and disruptive than methanol and less likely to cause death unless large amounts are ingested. Some denaturants used to discourage ingestion of ethanol fuel may be toxic.

Two other aspects of alcohol fuels which require careful attention to handling are the risk of fire and explosions in confined spaces. Wide flammability limits for both methanol and ethanol and low vapour pressures are characteristics which can lead to explosive air/vapour mixtures under typical storage conditions. Small additions of hydrocarbons have been shown to substantially reduce the potential for explosions. Existing handling procedures should suffice, based on the long history of handling alcohol. In the event of widespread introduction, correct handling procedures must be clearly identified and made generally available at all points where the alcohols require storage or transmission in enclosed containers. As applied to tank cars for example, these include careful control of potential ignition sources, electrical grounding of the tank car prior to any pipe or vent connections and the use of flame arrestors on vent connections.

Both methanol and ethanol have a characteristic low flame luminosity which may pose some difficulty in detecting fires. A practical approach to resolving this problem will be the addition of a colourant. Small amounts of hydrocarbons will also relieve the problem. Special firefighting techniques are required, particularly in the selection of firefighting foams. Current foams used for petroleum fires smother the fire with air bubbles and suppress the release of flammable vapours. Any water containing foam will be ineffective for alcohol fires as the alcohols will mix with the water. Water alone may be ineffective; methanol, for example, remains a flammable liquid even when diluted to 21 percent. Special alcohol foams such as polymeric polar solvent foams are required.

4.1.2 Regulatory environment

All inter-provincial transport of goods by any mode and intra-provincial transport of goods by rail, marine, air and pipelines is under the primary jurisdiction of the federal government. Intra-provincial transport by road is a provincial jurisdiction.

At present, four federal acts are used to control the movement of petroleum and petroleum products; one for each of road, marine, rail and pipeline transport. The same acts are used for alcohol for their movement by rail and road. These are the only modes currently used for alcohol transport. The acts are:

- Motor Vehicle Transport Act for movement by road, administered by the Canadian Transport Commission.
- Canadian Shipping Act for movement by the marine mode, administered by the Canadian Coast Guard.
- Canada Railway Act for movement by rail, administered by the Canadian Transport Commission.
- National Energy Board Act for movement by pipeline, administered by the National Energy Board.

Each province has established their own regulations for product movement by road within their jurisdiction.

It is anticipated that the federal Transportation of Dangerous Goods Act, Chapter 36 will be in effect by the end of 1983. The intent of this act is to provide a single set of safety standards, regulations and requirements across the country. The act will replace or partially replace existing federal and provincial regulations on the transportation of dangerous goods. As a public safety law, the federal government has prime jurisdiction. The law will apply to all modes except pipeline. Its application will cover all loading and unloading requirments in the commercial cycle which may affect safety, including dispensing into retail tanks. Where necessary, new or amended provincial legislation will be enacted to complement the federal regulation. The law will specify:

- materials and handling requirements.
- transport personnel training.
- safety standards.
- firefighting techniques.
- packaging and labeling requirements.

- notifications and accident report requirements.

Alcohols and gasoline will be categorized under Class 3: Flammable and Combustible Liquids. Ethanol will have flammable designation. Methanol will be designated flammable and toxic and will have more stringent safety standards. Alcohol and gasoline blends may be classified in the No-specific (NSA) category and safety provisions would be established based on the toxicity and flammable characteristics of the blends relative to the volume of alcohol in the blend. Alternatively, low level blends may be simply classified within the gasoline category, as the specification characteristics of both will be substantially similar.

The transportation and distribution requirements of alcohol fuels will be essentially similar to those required for existing shipment practices of alcohol. A comprehensive set of regulations will be established by the Transportation of Dangerous Goods Act as soon as it is enacted. Grey areas that still exist for the classification of alcohol blends should be easily resolved.

4.2 UTILIZATION OF ALCOHOL FUELS

No utilization standards have been formulated by regulatory agencies for neat or blended alcohol fuels. Current fuels' standards are essentially geared to regulate gasoline or diesel fuels, although some areas have been revised to accommodate propane and compressed natural gas. The characteristics of alcohol fuels suggest several areas which will require review. These include:

- fuel quality.
- vehicle safety.
- emissions.
- vehicle insurance and warranty coverage.
- fuel efficiency.
- taxation.

Each is discussed below.

4.2.1 Fuel quality

The Canadian General Standards Board (CGSB) sets fuel quality standards and testing procedures. Regulation of the standards is under the jurisdiction of provincial governments, although only Ontario, Quebec and Alberta include such standards as part of provincial regulations.

As discussed in previous sections, the physical and chemical properties of alcohol fuels are substantially different from conventional fuels. These differences place somewhat different demands on engines than gasoline or diesel. To ensure proper engine performance and consistent fuel quality, it will be necessary to develop fuel specifications for neat and blended fuels. There is general consensus on the problem areas to be addressed and general approaches to resolve them. There is to date, no universal or formal consensus on what the specifications should be. Major problem areas which are being addressed in most alcohol fuel research programs include phase separation, cold start and warm-up requirements, lubrication requirements and the need for fuel additives in different amounts or composition than conventional hydrocarbon fuels. The significance of these issues vary by the type of alcohol considered (i.e. methanol or ethanol) and the nature of their application (i.e. neat or blends).

Testing procedures adopted by the CGSB are identical to those used by the Americal Society of Testing and Materials (ASTM) in the United States. These procedures are broadly concerned with establishing limits to distillation, reid vapour pressure, oxidation stability, lead, corrosion and colour. The ASTM currently has informal specifications for 10 percent ethanol with gasoline blends which will be adopted by the CGSB. There are no specifications for neat alcohol or methanol blends, although such specifications are reported to be in the process of being developed for oxygenated fuels. The development of formal fuel specifications is an evolutionary and lengthy process involving the standards groups, the fuels industry and the auto industry. Draft specs are proposed, tested, modified and drafted several times. At some point, interim specifications will allow commercial-level application at which point refinements will be made over time and the specification finalized.

Current testing programs with methanol blends will encourage the introduction of interim specifications (assuming the test programs are successful). Specifications for neat fuel applications will be somewhat more difficult due to the lack of demonstration and experience with these fuels under Canadian conditions.

Another aspect of fuel quality, related to fuel specification is storage stability. Current experience suggests that neat and blended alcohols have storage stability about equal to current gasolines. Methanol blends require the addition of co-solvents to maintain equal storage stability characteristics.

4.2.2 Vehicle safety

The Motor Vehicle Safety Act entitles Transport Canada to issue and enforce Federal Safety Standards to which all automobiles, multi-purpose passenger vehicles, trucks, trailers, and buses must comply at the time of manufacture. Current regulations apply to fuels whose boiling point is over 0°C. These fuels include gasoline and neat and blended alcohols. Transport Canada is evaluating the need to establish safety requirements for alcohol fuels.

The only test required to establish vehicle safety with respect to fuels containment is the Barrier Crash Test. This test is completed for front, rear, side and roll-over impacts. Tank integrity is tested after the barrier crashes. No tests have been performed on alcohol fuelled vehicles. The test procedures and criteria should be the same as for gasoline vehicles. Representatives of Transport Canada suggest that current regulations are unlikely to impede the commercialization of alcohol fuels, from a vehicle safety perspective.

4.2.3 Emissions

The federal Motor Vehicles Safety Act also sets emission standards for gasoline and diesel. Emissions are regulated for hydrocarbons, carbon monoxide and nitrogen oxides for new vehicles. Unregulated emissions include aldehyde, ammonia, smoke, particulates and sulphur compounds. Current standards do not address all emissions of alternative fuels.

Vehicle emissions of alcohol fuel combustion products have received more extensive and detailed characterization than any other environmental and health effect of using alcohol fuels. Although well characterized, laboratory test results must be approached with some caution. Actual emissions will be a function of vehicle duty cycle, engine technology, ambient conditions, vehicle maintenance and the driving habits of the operator.

Figure 4.1 summarizes the experimental record relative to gasoline. Briefly:

- substantial reductions in reactive hydrocarbons and nitrogen oxides exhaust emissions are expected for neat methanol and to a lesser extent ethanol. Although total hydrocarbons will not decline significantly and may increase depending on the equivalence ratio, their reactivity will be substantially less.

- substantial reductions in polynuclear aromatics with neat alcohols and blends. Although emitted in small quantities from conventional fuels, these compounds are highly toxic and carcinogenic.

- no significant changes in carbon monoxide emissions.

- increased aldehyde emissions are expected with neat alcohols and blends. Aldehydes are photochemically reactive and highly irritating to mucous membranes. Although not currently regulated, the widespread use of alcohols may require a specific control strategy. Aldehyde emissions from neat methanol (primarily formaldehyde) are typically from two to four times those from gasoline. Ten fold increases have been reported. The dominant aldehyde from ethanol combustion is acetaldehyde. Exhaust catalysts are effective in controlling aldehydes, particularly three-way catalysts.

- particulate emissions will be essentially non-existent with neat alcohols.

TABLE 4.1

EMISSION CHANGES (COMPARED TO GASOLINE) FROM USE OF ALCOHOL FUELS AND BLENDS

Pollutant/Fuel	Methanol	Methanol/Gasoline	Ethanol	Ethanol/Gasoline
Hydrocarbon or Unburned Fuels	About the same or slightly higher, but much less photochemically reactive, and virtual elimination of polynuclear aromatics, can be catalytically controlled.	May go up or down in unmodified vehicles, unchanged when equivalence ratio remains constant. Composition changes, tho. and polynuclear aromatics go down. Can be controlled. Higher evaporative emissions.	Not very much data, should be about the same or higher but less reactive. Expected reduction in polynuclear aromatics.	May go up or down in unmodified vehicles, about the same when equivalence ratio remains constant; composition may change, expected reduction in polynuclear aromatics. Evaporative emissions up.
Carbon Monoxide	About the same, slightly less for rich mixtures; can be catalytically controlled; primarily a function of equivalence ratio.	Essentially unchanged if equivalence ratio remains constant, lower if leaning is allowed to occur.	About the same, can be controlled, primarily a function of equivalence ratio.	Decrease in unmodified vehicles (i.e. leaning occurs), about the same when equivalence ratio remains constant.
Nitrogen Oxides	1/3 to 2/3 less at same A/F ratio, can be lowered further by going very lean; can be controlled.	Mixed, decreases when equivalence ratio is held constant, but may increase from fuel "leaning" effect in unmodified vehicles.	Lower, but not as low as with methanol; can be controlled.	Slight effect, small decrease when equivalence ratio is held constant, but may increase or decrease further from fuel "leaning" effect in unmodified vehicles.
Oxygenated Compounds	Much higher aldehydes, particularly significant with precatalyst vehicles.	Aldehydes increase somewhat, most significant in precatalyst vehicles.	Much higher aldehydes, particularly significant with precatalyst vehicles.	Aldehydes increase, most significant in precatalyst vehicles.
Particulates	Virtually none.	Little data.	Expected to be near zero.	Little data, no significant change expected.

Over the short-term, it is unlikely that emission guidelines for alcohol fuels will be required. Should substantial penetrations occur, an examination of current standards may be necessary. It has been suggested that should emission standards be established in the United States, they might be used as an interim measure in Canada.

There is increasing concern in the U.S., however, that establishing these standards could be a costly and lengthy exercise. The vehicle certification process is potentially one of the largest environmental and regulatory hurdles that alternatives to petroleum transportation fuels will face on their way to commercialization. There are impediments in the existing laws to the introduction of alternatives such as alcohols and alcohol-gasoline blends. These barriers have received little attention. Their scope will probably not be fully appreciated until a major effort is undertaken to meet the vehicle emissions standards with which cars and trucks now must routinely comply using traditional petroleum-based fuels. The U.S. Clean Air Act of 1977 binds the automobile industry and the Environmental Protection Agency (EPA.) The Clean Air Act provides for standardized test fuels as well as standardized vehicle test procedures. The standard fuel is Indolene, a closely controlled gasoline for emissions testing of spark ignition engine vehicles and a similarly standardized diesel test fuel for diesel engine vehicles.

No fuel or fuel additive (for example, alcohol used in a blend with gasoline or by itself as a "neat" fuel) may be introduced into trade unless it is "substantially similar" to fuels or fuel additives used in certifying 1975 and subsequent model year vehicles. EPA's interpretation is based on three technical criteria. Waivers of Section 211(f) will be granted for fuels that satisfy the first and for fuel additives that satisfy any of the three. The criteria are as follows:

- the fuel or fuel additive contains either carbon or hydrogen only or carbon, hydrogen and oxygen only and is sold as or in an unleaded fuel with final chemical and physical properties typical of those of the unleaded fuel used in certifying 1975 and later vehicles, or;

- the fuel additive contains carbon, hydrogen and nitrogen or carbon, hydrogen, oxygen and nitrogen and its concentration in the finished fuel is not more than 0.25 weight percent, or;

- the fuel additive has a molecular structure and chemical composition identical to a fuel additive used in certifying 1975 or later vehicles and it's concentration in unleaded gasoline (by weight) has not been increased by more than 50 percent.

Waivers have been granted for methyl tertiary butyl ether (MTBE), tertiary butyl alcohol (TBA) and an oxygen-bearing fuel additive (oxynol) produced by ARCO. These waivers are for the materials used as gasoline additives but not as bulk fuels in and of themselves. A waiver requested for Gasohol (10% ethyl alcohol - 90% unleaded gasoline) was not explicitly granted nor refused pending the

development of further data and in view of the fact that it represented only a minuscule fraction of U.S. gasoline consumption. The EPA allowed the continued marketing of Gasohol.

To bring an alternative fuel to market, the supplier must prove that it does not create a greater air quality hazard than exists with current fuels, nor contribute to the failure of any emissions-related component of the vehicle. Alcohols are different enough chemically from the petroleum hydrocarbons that current engines cannot accommodate fuels from either group interchangeably while in a single state of tune and adjustment. Even in the case of an alternative such as ethanol, used in a mild (10%) blend with gasoline, the difference in fuel chemistry between the blend and straight gasoline is significant. Although both might yield acceptable vehicle operation, and either might permit the vehicle to comply with the applicable emissions standards, the Clean Air Act interpretation preclude the sale of a blend until cars which will use it are shown to be capable of being certified with it.

Any fuel not "substantially similar" to that used in certifying 1975 and later model year vehicles cannot be burned in vehicles until emission conformity is demonstrated. Assuming that the implementation of alcohol fuels will proceed in an evolutionary fashion over a period of years, at some point conventional and alternative fuels will co-exist. Under these conditions, dual automotive emission certification programs might be required. This would complicate an already difficult and expensive process for the auto industry.

The automotive emissions certification process in the U.S., comprises several major phases, each of considerable magnitude and complexity.

- certification application submission
- 50,000 mile durability vehicle testing
- 4,000 mile emission data vehicle testing
- running change evaluation
- selective enforcement audit

The number of vehicles and costs required for the test and evaluation phases range from 50 or more vehicles and $100,000 per vehicle for 50,000 mile durability testing, to 200-300 vehicles and $40,000 per vehicle for 4,000 mile emission data vehicle testing. A failure at any point in the process negates the entire investment of time, money and effort in achieving compliance. The process must be repeated if such vehicles are to be produced and sold.

Any new fuel requiring a significantly different range of air-fuel ratios for optimal combustion will require the EPA to consider whether the present certification fuel (Indolene, a standardized gasoline for emission test purposes)

provides a satisfactory representation of the new fuel. If it does not, a new certification fuel must be defined. If the two certification fuels are appreciably different in their air-fuel ratio requirements, the optimal engine calibrations for each will also be different. If the engine and vehicle is optimized for one fuel and certification is achieved, it is unlikely that the vehicle could also qualify for a Certificate of Compliance on the other test fuel.

To qualify on both fuels, vehicle design standards would be more stringent and costly than is now the case. If certification were required on both fuels, the effort, expense and risk of disqualification would be doubled.

The possibility exists that at some time in the relatively near future, automotive manufacturers may be faced with the legal necessity of certifying their vehicles on two or more fuels. At best, the costs and logistics of performing the expanded certification testing will be an imposing burden.

4.2.4 Insurance and warranty coverage

Vehicle warranty coverage has been discussed for retrofitted and OEM-optimized vehicles in earlier sections. In general, any modification made to an engine or vehicle in the course of an alcohol fuel retrofit will void the OEM's warranty on the item or system involved and probably on the whole engine or vehicle. OEM-optimized vehicles will retain the manufacturer's warranty or at least a modified version thereof.

Insurance coverage will apparently not be affected, in the absence of any actuarial data suggesting a "worrisome trend" of higher accident involvement or casualty loss for alcohol-fuelled vehicles. Low-level blend fuels have been commercialized in the U.S. and neither warranties nor insurance coverage has been affected. Any issue that may arise in the future will probably center on neat fuels. In the case of OEM-optimized vehicles, it is unlikely that insurance coverage will be affected.

4.2.5 Fuel consumption and taxation

Current fuel consmption standards and taxation are applied as a function of fuel volume (i.e. l/100 Km or dollars per litre). The lower energy density of alcohols places them at a significant disadvantage to gasoline or diesel even though they are more energy efficient fuels.

The as yet unproclaimed Motor Vehicle Fuel Consumption Standards Act will permit Energy Mines and Resources Canada to develop Canadian standards for average fuel economy for new manufacturers' fleet vehicles. Current standards take the form of voluntary guidelines based on United States' standards for petroleum based fuels. As currently established, these standards would place neat methanol at a 2:1 disadvantage to gasoline. The energy density per volume of methanol is about half that of gasoline. In theory, the Fuel Consumption Act administered by EMR could alleviate this disadvantage by allowing credits or establishing lower equivalent ratings for alternative fuels relative to gasoline.

Provincial and federal taxation is also based on fuel volume. Methanol and ethanol will bear a disproportionate tax burden compared to gasoline or diesel fuel. A more equitable tax system would be to tax on a volume equivalence ratio to gasoline (i.e. number of litres of methanol or ethanol required to replace one litre of gasoline) or alternatively to tax the fuel energy content per volume of fuel (i.e. $/GJ). In the former case, for example, about 1.5 to 1.6 l of methanol is required to replace one litre of gasoline. A volume replacement tax for methanol would be two-thirds that of gasoline. Taxation on fuel energy content would provide an advantage for fuels such as methanol and ethanol which have better thermal energy efficiency (i.e. more Km per GJ of energy). In this case, the effective tax for the alcohols would also be less than for gasoline.

5. ALCOHOL FUEL MARKET ECONOMICS

Once vehicle owners are confident that the regulatory and technical issues discussed in the previous chapter have been resolved, they will be in a position to evaluate the attractiveness of alcohol fuel in the context of their individual vehicle applications. At this point, the choice of one fuel over another will largely be based on its economic attractiveness. As with other alternative fuels, this will be a function of the fuel supply price plus any costs associated with utilizing the fuel, such as the incremental costs of vehicle modifications. As alcohols are currently not used as a vehicle fuel to any practical extent, the issue of pricing is somewhat uncertain. The value of alcohols as blending agents will depend on its ability to satisfy gasoline octane requirements at the refinery. This in turn is influenced by supply prices of the alcohol and the costs to develop the necessary distribution and marketing infrastructure. Neat alcohols in their turn must be priced at the pump at a level sufficiently low relative to gasoline that any vehicle costs to use the fuel are recovered in a reasonable length of time. Again, the issues of establishing an effective distribution and marketing infrastructure must be evaluated.

This chapter will review these requirements. Production prices of the alcohols and the costs required to bring them to market will be established for both neat and blended fuels.

5.1 PRODUCTION

There are numerous production processes which can produce methanol and ethanol from a variety of feedstocks. Some are commercially proven, others have yet to be demonstrated.

Methanol is currently produced by steam reforming natural gas to produce an industrial grade feedstock for use in other industries (i.e. formaldehyde resins) or for export. Alternative methods of producing methanol include the use of feedstocks such as coal, wood or peat. In these cases, the feedstock is gasified to produce a synthesis gas which in turn is used as a building block for methanol synthesis. A variation is to use both natural gas and wood. Natural gas, coal and wood can also be used to produce a methyl fuel, which, unlike the higher purity industrial grade methanol, will contain a mixture of alcohols (about 80 percent methanol, 20 percent ethanol, propanol and butanol). Methyl fuel offers advantages over pure methanol as a transportation fuel as it reduces the likelihood of phase separation in gasoline/alcohol blends and reduces vapour lock problems in neat fuel applications. Industrial grade methanol can be engineered to provide the same benefits through subsequent treatment with fuel additives.

Ethanol is produced for both industrial markets and as an alcohol beverage. The fermentation of grains has been used for centuries to produce beverages. The main commercial route to industrial grade ethanol is the hydration of ethylene. This process reacts ethylene with steam in the presence of a catalyst to produce

ethanol. Ethanol may be produced by any of these processes to produce a transportation fuel. Less proven technologies are at various stages of development. An interesting possibility is the fermentation of wood through acid or enzymatic hydrolysis. Ethanol may also be synthesized from natural gas or coal by methods similar to the production of methanol. The production economics of the latter are substantially higher than is the case for methanol.

The main production technologies for both methanol and ethanol which appear to be commercially practicable over the short to medium term are:

Methanol	Ethanol
- steam reforming natural gas	- fermentation of grains
- wood or coal gasification	- fermentation of wood
- natural gas/wood combinations	- hydration of ethylene

The production economics of each process are substantially different due to variations in feedstock prices and capital requirements.

In terms of available supply, current methanol production is approximately 1.82 million tonnes per year. The industry has witnessed substantial growth over the past few years increasing capacity from 430,000 tonnes in 1980 to the present level. As only about 250,000 tonnes are required as domestic industrial feedstocks, this new capacity has been established to serve export markets, primarily to the United States and Pacific Rim countries. As export markets tighten due to an emerging global methanol surplus, methanol, currently exported, may become a readily available source of transportation fuel. Current exports of methanol amount to roughly five percent of the equivalent gasoline market. Under conditions of commercial introduction into transportation markets, substantial increases in capacity might be required.

Although there are a number of distilleries providing potable ethanol, few plants will be capable or likely to produce a fuel grade ethanol. Those that are include:

- ethanol fermentation plant in Winnipeg for blending with gasoline distributed by Mohawk Oil. Barley is the feedstock. Capacity is roughly 9,200 m^3 per year. Expansion plans are under evaluation as is consideration of the use of cellulosics (wood) as a feedstock.

- ethylene hydration facility in Montreal with a rated capacity of 69,000 m^3 per year.

- ethanol from sulphite liquors at Thorold Ontario with production capacity of 6,400 m^3 per year.

It is clear that any significant penetration of ethanol into the transportation sector would require substantial investment in production capacity. Potential ethylene supplies for hydration have been forecast as high as 3.5 million tonnes by 1990. Of the fermentation routes, wood will likely be the source of low value feedstock, although the conversion process itself remains to be proven. Other fermentation feedstocks could be grains such as barley, wheat or corn. Relative to wood, these feedstocks are substantially more expensive, but use commercially available conversion processes.

Production cost estimates for both methanol and ethanol are difficult to establish. Existing methanol producers have plants of varying ages which affects capital recovery costs and different contractual arrangements for natural gas (which can account for 40 to 50 percent of production costs). The lack of commercial facilities for other feedstocks, whether to produce methanol or ethanol makes it difficult to accurately predict production costs.

Numerous attempts have been made to establish these costs for processes using the various feedstock. The most comprehensive and current estimates (55) suggest the following production costs by feedstock in 1982 dollars per GJ.

Methanol		Ethanol	
natural gas	$ 10.07	ethylene	$ 16.24
wood & natural gas	12.08	grains	18.21-20.88
wood	13.79	wood	21.19

The only cost which can be verified is the production of methanol from natural gas. Informal approaches to the industry suggest prices of $7.90 - $8.00 per GJ from existing facilities at natural gas prices similar to those in the P.P.S. study. The observed discrepancy is likely due to differences in capital cost recovery assumptions of a new vs. old plant. Industry production prices may be even lower depending on the actual cost of the feedstock. This is commercially confidential information. Other production cost estimates noted above are for the most part, derived for processes which are not commercially available.

By way of comparison, the production cost of regular unleaded gasoline at the end of 1982 is estimated to be $7.80 per GJ. Only methanol from natural gas compares favourably. The production cost of each fuel and feedstock are shown below as a percentage of regular unleaded gasoline.

Methanol from natural gas	
new plant	129%
existing plant (estimate)	102
Methanol from natural gas and wood	155
Methanol from wood	177
Ethanol from ethylene	208
Ethanol from grains	233-268
Ethanol from wood	272

At present, ethanol, from any source, and methanol from wood alone or in combination with natural gas, do not appear to be attractive candidates as transportation fuels. Over time, improvements in conversion efficiency may narrow the gap to some extent. In some cases, locally available feedstocks (waste or spoiled agriculture products, for example) may be available at low cost. Either condition would improve production economics. On balance, only methanol from natural gas appears to be a short to medium term source of alcohol fuel for large scale introduction into the national transportation fuel market. Other processes may provide economical sources of supply for local or regional markets. On farm use of anhydrous or aqueous ethanol may be a practical application where feedstocks are available at low cost. Production in this case would occur at a very small scale for individual farms, rising progressively to meet the collective needs of a group of users, in a cooperative, for example. With the right technology and low cost feedstocks, methanol may be produced for regional markets. An example is a proposed 400,000 tonnes per year plant to be located in Ontario. This plant will use a combination of wood and natural gas feedstocks.

5.2 TRANSPORTATION AND MARKETING

Neither methanol nor ethanol have an established transportation or marketing infrastructure to support their utilization as blended or neat fuels. To the greatest extent possible, their introduction into the transportation market at significant levels must use the existing hydrocarbon fuels infrastructure. At several points along this system, it has yet to be demonstrated that alcohol will be a compatible product. The distribution requirements and problems will be somewhat different for each of the blends and neat alcohol options. The delivery systems will generally be common between methanol and ethanol.

5.2.1 Neat alcohol

The only practical approach to moving large quantities of alcohols to national markets will be by utilizing pipelines or unit tank trains. Regionally supplied markets will undoubtedly be limited to trains. The smaller, locally supplied markets will be restricted to tanker cars.

Over the short to medium term methanol from natural gas produced in Alberta and British Columbia could be a source of fuel supply for national markets. If existing petroleum product pipelines are utilized, the eastern limit of the market will be the Kingston/Ottawa area. Where rail is utilized, the market area could be extended to the East Coast. For most markets, the decision to pipeline or move by tanker rail will depend on their relative economics, the quantities to be shipped, any technical limitations presented by the fuel and the configuration of the distribution system.

Pipelines

The transportation of large volumes of methanol will undoubtedly be cheaper by pipelining. Over the short term, this option will be restricted by the lack of

comprehensive testing on the compatibility of methanol in existing pipelines. The methanol manufacturers will likely be required to ensure that the product causes no damage to the pipeline or to the quality of the products batched immediately in front or behind the methanol. To date, there has been no definitive testing of the materials compatibility of methanol in pipeline systems.

As alcohol is a solvent and an excellent cleaning agent, it will tend to pick up contaminants as it passes through the pipeline. To keep contamination to a minimum, only clean product pipelines can be considered for methanol transportation. These pipelines carry finished products from refineries or natural gas liquids (NGL). For the most part, they parallel the transportation of crude oil in the InterProvincial Pipeline system (IPPL).

- from Edmonton
  - one line carries crude oil to Superior
  - one line carries NGL to Superior
  - one line carries finished products to Gretna, Manitoba

- from Superior
  - one line carries crude oil to Sarnia
  - one line carries NGL to Sarnia

The eastern destination is the refinery complexes at Sarnia. Shipping from Sarnia to eastern retail markets will require the clean products lines of the major oil refiners. These pipelines tie into the various marketing terminals of each firm for subsequent delivery to retail locations. The main lines are:

- Imperial Pipeline - shipping to London, Hamilton and Toronto. This line is owned by Imperial Oil.

- Sun Canadian Pipeline - shipping to London, Hamilton and Toronto. This line is owned by Suncor and Shell Canada.

Both lines can deliver product to most marketing terminals in the area served and carry products for other shippers. An additional finished product pipeline, the Trans Northern, owned by a consortium of oil companies, operates from Toronto to Ottawa with a "yo-yo" (multi-directional) link to Montreal. Again, the alcohol manufacturer must assure the pipeline operators that no damage to the pipeline or other products will occur. From each marketing terminal the methanol will be distributed by tanker car to the retail facility.

The utilization of neat methanol will require a cold start enhancing additive. Possibilities include 5 percent volume of light hydrocarbons (C_4, C_5) or 10 to 15 percent by volume whole gasoline. At some point in the distribution system, these additives must be blended into the methanol. In theory, this may occur at the refinery, the marketing terminal or the pump. As the transportation of the methanol relies on the infrastructure of the refineries and physically passes through the area where these refineries are located, the simplest approach would

be to blend at the refineries. The other options compound the difficulty of the marketing system by causing two products rather than one to be handled and stored. The various options are under evaluation by Energy, Mines and Resources, Canada.

The costs to market neat methanol will be made up of capital investments to store the methanol at various points along the system and the pipeline transmission charges. Where existing storage tanks can be used, additional capital investment will not be required.

Table 5.1 provides an example of the bulk storage requirements to serve the Toronto market (exclusive of retail requirements). At individual tank sizes of 7,900 m^3, the total cost of new tanks would be $3 million, for 15,900 m^3, the cost would be about $6 million. Through the entire system from the producer to the marketing terminal, a total of between 63,200 to 127,200 m^3 of tankage would be required. To the extent that national markets are being served, incremental tankage requirements would be necessary at each marketing terminal or storage area. Distribution at the scale envisioned above would be in excess of total current exports. The level of tankage in absolute amounts is probably quite close to actual requirements. Given the volume of methanol handled and the modest level of investment required which would be depreciated over 15 to 20 years, the added cost per litre of fuel handled would be negligible once the infrastructure is fully utilized.

Service stations will likely require new tanks to be installed to ensure compatibility with neat methanol. Current estimates place the required tank costs at $13,500 for 45 m^3 tank; and $27,000 for 90 m^3 tank. These costs would also be negligible over the life of the tank, adding little, if any, to the retail cost of the methanol.

The pipelining charges and costs associated with delivery to retail locations are more significant. Based on current NGL rates, the pipeline charges are estimated to amount to about $10.30 per thousand m^3 or roughly one cent per litre for the volume indicated above. Roughly two-thirds of this charge is from Edmonton to Sarnia, the balance from Sarnia to the various marketing terminals. Current experience with gasoline distribution suggests a charge of $8.80 per thousand m^3 or 0.9 cents per litre for truck delivery to retail locations. These combined charges will add about 1.9 cents per litre to the price of methanol.

Rail

The alternative is to ship by rail, either in unit tank car loads for large amounts or multiples of single cars for smaller amounts. In theory, this distribution mode could take one of two routes:

- shipment to terminals located close to the point of demand with hydrocarbons added at the terminal for distribution to retail locations.
- shipment direct to refineries for blending and subsequent distribution in product pipelines to marketing terminals.

TABLE 5.1

DISTRIBUTION TANKAGE REQUIREMENTS
EDMONTON TO TORONTO VIA PIPELINE

	Minimum (m^3)	Maximum (m^3)
Shipping Tank at Producer	7,900	15,900
IPPL Terminal (Edmonton)		
- Two tanks, one receiving, one shipping	15,800	31,800
IPPL Superior	7,900	15,900
Terminals at Sarnia		
- Receiving	7,900	15,900
- Blending	7,900	15,900
- Shipping	7,900	15,900
Terminals at Toronto	7,900	15,900
TOTAL:	63,200	127,200

The first option may prove to be impractical unless a decision is made to construct a dedicated methanol marketing terminal. Existing terminals owned by the major oil companies have no rail facilities. Forward shipment to the Sarnia refineries may be a practical requirement. The amount of tankage would be considerably reduced, with requirements only at the refinery and the product marketing terminal. For new tanks, these costs would be between $1.2 and $2.7 million. The cost of retail tanks would remain the same as already discussed as would distribution by tanker car to retail outlets.

The penalty which must be borne if distribution is carried out by rail car is the transportation charges. The number of cars on a unit train varys from 50 to 100. Unit trains receive a preferential rate. Anything smaller is added to existing trains servicing the area. The smaller the grouping, the higher the rate. Estimates of the total charges from producer through to a Toronto retail station have been made and are shown below in Table 5.2. Total shipments for unit trains are roughly half as expensive as single car transport, adding between 3.3 cents to 6.2 cents per litre to the cost of the methanol. Most of this cost is related to the rail charges.

TABLE 5.2

NEAT METHANOL DISTRIBUTION CHARGES - RAIL

	Single Car Rate to Sarnia	Unit Train Rate to Sarnia
	($/1,000 m^3)	($/1,000 m^3)
Edmonton to Sarnia - rail	$ 50.30	$ 21.06
Pipeline to Terminal	3.43	3.43
Truck to Retail Location	8.80	8.80
Total:	$ 62.53	$ 33.29
¢/Litre	6.2	3.3

These costs assume the refinery has adequate rail infrastructure to accommodate movement by this mode. Specifically, it is assumed that there is enough siding to accommodate the train, unloading facilities are sufficient to meet any time constraints, and that cars can be readily shifted during unloading. If these conditions cannot be met, costs could be much higher.

5.2.2 Blends

The marketing and distribution requirements for alcohol used for gasoline blending purposes will be similar to those for neat alcohol. The alcohol must be transported to a blending location for ultimate distribution to retail locations. The system must also contend with the need to add co-solvents to the alcohol prior to or in combination with the gasoline blending step. As with the neat fuels, the transportation system will rely on pipelines or rail for the movement of methanol from producers in the west, rail for methanol or ethanol produced for regional markets and tanker cars for alcohols produced locally and consumed close to the point of production.

Pipelines

Pipelining methanol for blending is unlikely over the short term due to the pipeline materials and product testing requirements already discussed for neat methanol. Once it has been demonstrated as practicable, and when methanol blends attain a significant market share, there are considerable advantages:

- pipelining charges are much less than rail charges as discussed in the last section.
- the pipeline system ties directly into the refineries in south-western Ontario for blending with gasoline.
- the downstream distribution and marketing infrastructure of the refineries can be readily utilized.

These advantages will probably preclude other options of blending at the marketing terminal or at the pump. Refinery blending will utilize the available infrastructure to the maximum extent possible, simplify the distribution system by requiring only one product to be handled rather than several, and provide a measure of quality control which cannot be matched by the other options. Seasonal variations to the gasoline blend specifications are more readily accomplished and the ability to correct any product quality problems is more practical at the refinery.

To minimize tankage and distribution costs, methanol and the required co-solvents should be blended at the alcohol producers plant. Over the short term, this may not be practical as existing sources of co-solvent are produced in the east while the methanol is produced in the west. Over the medium to long term, as the alcohol blends become more prevalent, co-solvent manufacture in the west from natural gas or natural gas derivatives would permit the blending of the co-solvent and methanol before entering the pipeline system.

The storage tank requirements discussed for neat methanol also apply to methanol blends. Sufficient capacity to store and blend current levels of methanol exports will require between 63,200 and 127,200 m^3 of tank capacity at

an estimated cost of between three and six million dollars. At initial low levels of demand, this volume of storage would be under-utilized and an investment of this magniture might be considered excessive. As the market grows and the installed capacity is more fully utilized, the investment cost quickly becomes negligible in terms of the volume of fuel handled.

Pipeline charges to Sarnia refineries will add about 0.68 cents per litre to the methanol/co-solvent purchase price when blending occurs at the producer's plant. From the refinery, the distribution and marketing costs will be the same for the blended fuel as for gasoline.

Rail

Over the short term, it is more likely that alcohol from the west will move by rail than by pipeline. If an intermediate alcohol storage terminal is feasible, this would be a logical blending location for the co-solvent whether produced domestically or imported from the United States. It could also serve any regionally produced alcohol which will most likely use rail as the dominant transportation mode. The terminal could then distribute the methanol/co-solvent blend either directly to retail locations for blending with gasoline at the pump or transhipped by rail to refineries. Quality control should be the primary determinant in deciding on where to blend. Blending at the refinery has obvious advantages as already discussed. If alcohols are viewed as a source of high quality octane and hence, as an additive to gasoline, refineries will be best able to ensure a uniform product.

If an intermediate alcohol terminal proves impractical, direct shipment of the methanol directly by rail will be the only option. As in other cases, it will be preferable to ship the methanol and co-solvent as a blend, rather than separately, to minimize tankage requirements.

Rail charges to a Toronto terminal, for example, will be roughly 2.1 cents per litre for a unit train and 4.2 cents per litre at single car rates. Additional distribution and marketing charges to retail locations will be the same as for gasoline. These are estimated to be 0.34 cents per litre for pipelining to marketing terminals and 0.87 cents per litre for tanker car delivery to the retail stations.

5.2.3 Remaining issues

While the preceding sections broadly map out the potential options for moving alcohols for application as neat or blended fuels, there are still a number of questions and problems to be addressed.

The extent to which the existing gasoline distribution infrastructure can be used for these fuels requires further clarification. Fuels which can use the same infrastructure are termed "fungible". Traditionally, the oil industry has exchanged products between competing companies. This is done to reduce capital and save transportation charges. Any marketer introducing a product that is not fungible is faced with the prospect of moving the product from the

production area to consumers at full cost. This would likely limit the available service area for the product. For example, unleaded regular gasoline is a fungible product. Consider three refineries located in:

- Sarnia
- Toronto
- Montreal

Each refiner would supply its own demands at each location and allow lifting privileges to the others. They would not necessarily exchange dollars in these transactions. They would be exchanging a fungible product. All would save transportation costs and possibly some terminal costs.

If any oxygenate is introduced into unleaded regular by only one refiner, then the product is no longer fungible and that savings mechanism is unavailable. If the refiner must "go it alone" the cost of doing so must be borne by the oxygenate.

For pipeline traffic, there are still a number of concerns, some of which have been briefly discussed in other sections. Remaining issues include:

- InterProvincial Pipeline's (IPPL) Edmonton terminal is not equipped to handle railcars or trucks. The producer must ship by pipeline. To what extent do current producers have this capacity?

- what are the specifications for transporting alcohol? To what extent can it accept sulphur, pentanes, colour compounds, etc. which it may come in contact with, and what levels are acceptable?

- will the alcohol remove the protective coating on the pipeline?

- what is the optimum batch size for pipeline movement.

- who supplies the tankage requirements along the IPPL system, the shipper or the carrier?

- how much buffer stock is required and at what locations? For shipments out of Superior, who supplies and how?

- who has responsibility for the quality of the product along the system?

- to what extent will the shipper be liable for any damage to the pipeline or quality of other batched products caused by the alcohol?

Movement by rail has several advantages relative to pipeline, especially in the early stages of market penetration. When a product is new to the marketplace, and the handling problems are uncertain, using the existing rail system eliminates problems of contamination and all handling systems are already in place. The industry has a substantial background in moving alcohols by rail.

Depending on the volume to be shipped, the rail rates may be negotiated. Movement by rail provides the flexibility to establish a dedicated alcohols terminal for transshipment to refineries or other marketing terminals. Rail movement has historically not been as reliable as pipeline, however, and is susceptible to adverse weather conditions and breakdowns.

Several problems remain to be addressed. For the producer, the size of the train, its frequency, route and handling must be negotiated with the carrier. Where unit trains are used, there must be sufficient tankage to maintain production schedules at the plant. There must be sufficient siding to accommodate the train and loading must be accomplished within an allocated time period. If unit trains are not used, an efficient means of moving loaded and empty cars to and away from the loading arms must be established.

The requirements for the receiver, whether a terminal or a refinery, include: sufficient siding to accommodate the train; unloading facilities sufficient to meet any time constraints; sufficient tankage; and a means of shifting the cars during unloading. The extent to which these conditions can be met at refineries has yet to be established. Existing oil product marketing terminals do not have the capacity for rail traffic. To provide this capacity would require a large capital investment as would the construction of central alcohol receiving terminals at major demand centres.

5.3 MARKET PRICES

The retail market price of alcohol fuels will be a function of alcohol production cost, transportation and marketing charges, material costs for blending requirements, retail margins and federal and provincial taxes. The retail pricing structure for neat alcohols is complicated by the lower energy density of these fuels relative to gasoline. Several alternative pricing options are presented in this chapter to address this problem. For alcohol blends, prices must reflect the value of alcohols to the refiner, whose primary interest is in securing an octane enhancing additive. Whether as a neat fuel or as a blend, the retail price must, of course, be at least as attractive, if not more so, to potential consumers as conventional gasoline.

This section will provide a context for viewing the prices of alcohol fuel in relation to gasoline over the time period to 1995. Retail pricing of alcohols as a transport fuel is a new requirement with little or no practical experience to draw upon. At the moment, there are many issues which remain to be resolved. Consequently, several assumptions have been necessary. These assumptions are specified, as appropriate.

5.3.1 Product price assumptions

Gasoline

The world oil market is presently in considerable flux. In contrast to previous estimates of ever increasing real oil prices, oil exporters are now expected to substantially decrease their prices over the next several years. The full extent of immediate price declines and the prospects for future oil prices is extremely difficult to predict at this time. The National Energy Board (56) has recently published a scenario whereby the real price of imported oil declines by 20 percent over the period 1982 to 1985 and remains constant thereafter (i.e. no real price increases to the year 2000). Both these assumptions reflect the view that recent softness in the world oil market and the large shut in oil production capacity of OPEC will militate against real price increases, at least in the 1980's and possibly the 1990's. This assumption will be used in this study. The price of imported oil is, therefore, assumed to decline from $44.71 ($35.00 U.S.) per barrel in 1980 to $34.75 ($27.82 U.S.) in 1985 and will remain at this level. These prices are in 1982 dollars.

As yet, it is unclear what effect declining international oil prices will have on domestic pricing policy and existing agreements with the producing provinces. Specifically, it is apparent that holding the "old oil" price component of the blended domestic price of oil to 75 percent of world price will be difficult under the current federal agreement with Alberta and Saskatchewan. Adjustments to a tier of other provincial or federal charges may be made to hold this level or alternatively old oil may be allowed to slowly approach world prices. However the pricing policy evolves, it is assumed that the domestic blended price will not exceed world oil prices. As indicated below, domestic oil prices may rise by only another 5 percent before reaching the world levels postulated by the National Energy Board. These considerations suggest the following blended domestic oil prices (in 1982 dollars):

- 1982, $33.20/bbl
- 1985, $34.75/bbl
- 1990, $34.75/bbl
- 1995, $34.75/bbl

Gasoline prices can be expected to increase only modestly in real terms due to the assumed stability in oil prices. The price of gasoline at the refinery can be expected to increase by 0.77¢ per litre for every one dollar per barrel increase in the price of crude. Federal and provincial taxes (federal excise tax at 9 percent of wholesale price and provincial road taxes at 20 percent in applicable

provinces) will add an additional 0.24¢ per litre for every one dollar per barrel increase in crude oil. Average Canadian retail gasoline prices over the study period (in 1982 dollars) are therefore assumed to be:

	¢/l	$/GJ
1982	42.2	12.18
1985	44.0	12.64
1990	44.0	12.64
1995	44.0	12.64

Methanol

As indicated in Section 5.1, steam reforming of natural gas is likely to be the most cost effective means of producing methanol for the foreseeable future. In combination with the fact that substantial capacity over and above domestic requirements is already in place from western producers, steam reforming natural gas is the basis for estimating methanol costs in this study.

Methanol production costs are influenced to a large extent by the price of natural gas. These prices are currently regulated by the federal pricing agreement with the Alberta government. Toronto city gate price for natural gas is to be no more than 65 percent of the equivalent energy value of crude prices. City gate prices in Alberta will be determined by provincial pricing policies, within the limitations of the pricing agreement. It is assumed that Alberta prices are set at a level comparable to the Toronto city gate less the Trans Canada Pipeline transportation tariff charges. These charges are estimated to be $1.50/GJ and are assumed to remain unchanged in constant 1982 dollars over the study period. Upon the expiry of the provision of the federal/provincial pricing agreements in 1986, it is further assumed that natural prices will gradually increase to 70 percent and 75 percent of crude oil prices in 1990 and 1995 respectively. Such a trend is consistent with, although a little lower than, recent submissions to the National Energy Board. Based on these considerations, natural gas prices are forecast to increase by about 20 to 35 percent over the study period.

	Toronto City Gate		Alberta
	$/GJ	% crude	$/GJ
1982	3.52	65	2.02
1985	3.68	65	2.18
1990	3.97	70	2.47
1995	4.26	75	2.76

While natural gas prices are an important element in establishing the price of methanol, actual prices paid by manufacturers is confidential information. Informal discussions with producers suggest a production with return on investment of 11.0¢/l at gas prices of $1.42/GJ and 14.3¢/l at $2.37/GJ. For every 1 percent rise in natural gas prices, methanol costs increase by 0.45 percent. On this basis, methanol production costs in constant 1982 dollars are forecast to increase by 20 percent by the year 1995.

	¢/l	$/GJ
1982	13.1	8.08
1985	13.7	8.44
1990	14.6	9.05
1995	15.6	9.66

To the extent that the producer's actual natural gas contracts are lower than those assumed, methanol costs will be lower. Overcapacity for methanol will also persist in international markets, at least until the latter part of the decade. This may also serve to depress methanol prices below those forecast for this study. Weak markets may encourage discounting to an emerging transportation fuel market.

Ethanol

The production cost estimates for ethanol reviewed in Section 5.1 clearly indicate that ethanol is not competitive, on its own merits, with gasoline or methanol produced from natural gas. Future ethanol prices will depend largely on unpredictable technology advances for the various processes and on the cost of feedstocks.

Feedstock costs account for roughly 70 percent of the ethanol product cost for barley, corn and wheat, for example. Reducing ethanol production costs to levels similar to methanol from natural gas would require a 60 to 80 percent reduction in the cost of these feedstocks.

Feedstock	Ethanol production cost ($/GJ)	1982 feedstock Cost ($/tonnes)	Required feedstock Cost ($/tonnes)
Barley	18.21	99	42.60
Corn	20.07	129	38.70
Wheat	20.88	125	27.50

While product commodity markets typically undergo wide swings in prices, it is improbable that such reductions are either realistic or sustainable. To the

extent that spoiled or excess crops can be made available at low cost, ethanol production costs would be more favourable. This condition would likely be limited to a local market such as an agricultural cooperative.

Technology advances, improved conversion efficiency or alternative feedstocks may improve the competitive position of ethanol, but these effects are difficult to predict. High yield, low cost feedstocks such as jerusalem artichokes show promise as do developments in cellulosic feedstock processing.

For all practical purposes, ethanol is unlikely to be an attractive alternative fuel candidate for national transportation markets without substantial reductions in production prices or considerable government assistance. For this reason, ethanol is not considered further.

5.3.2 Neat methanol retail prices

The retail price of neat methanol will be a function of numerous costs, in addition to an adequate return on its production. These include:

- all transportation charges and distribution costs - pipeline or rail charges to a refinery location (assumed), distribution to marketing terminals and distribution to retail locations.
- refinery requirements - including additives for cold start enhancement (10-15 percent whole gasoline) and an assumed 10 percent mark-up on methanol purchase price to offer incentive and offset any tankage and handling cost.
- retail margin - calculated as 8 percent of refinery gate price.
- federal and provincial taxes - federal tax of 9 percent on wholesale price. Federal excise taxes apply only to gasoline and are not assessed. An average 20 percent provincial road tax assessed on posted price after federal tax is assumed.

An example of the costing calculation using 1982 methanol production costs is shown in Table 5.3, assuming Toronto retail locations. Retail neat methanol prices in constant 1982 dollars over the time period to 1995 are shown below:

	1982	1985	1990	1995
Retail price (¢/l) (excluding taxes)	20.89	21.65	22.63	23.91
Taxes (¢/l)	5.85	6.07	6.34	6.65
Retail price with taxes (¢/l)	26.74	27.72	28.97	30.56

TABLE 5.3

RETAIL PRICE COSTING EXAMPLE FOR NEAT METHANOL (1982)

	¢/Litre	
Cost to Refiner		
- methanol cost	13.10	
- pipeline charges	0.68	
- refiner margin	1.43	
- Cold start enhancing	3.00	
Refinery Gate Price:		18.21
Cost to Retail (net of taxes)		
- transmission to marketing terminals	0.34	
- truck delivery to retail	0.88	
- Retail margin	1.46	
Retail Price Increment:		2.68
Total Retail Price Excluding Taxes:		20.89
Taxes		
- federal excise tax	n.a.	
- federal sales tax	1.64	
- provincial road tax	4.21	
Total Taxes:		5.85
Total Price including tax:		26.74

These are the actual pump prices paid by consumers. Due to differences in energy density and fuel utilization efficiency, they cannot be directly compared to gasoline prices. The effective price paid by consumers relative to gasoline must reflect these differences. On an energy basis, 1.92 litres of methanol is required to yield the same energy content as one litre of gasoline. Methanol's greater fuel utilization efficiency, however, means that only 1.5 to 1.6 litres of methanol is required to replace one litre of gasoline. Current government taxation policy is on a volume, not a replacement basis. The effective tax on gasoline will be an equivalent energy rather than a replacement volume basis. Table 5.4 shows the difference in effective utilization prices of methanol vs. gasoline, under alternative taxation options.

- effective price (current tax) - provincial and federal taxes are calculated on an equal volume basis. Other elements of the price are shown as their effective replacement price relative to gasoline.

- effective price (replacement tax) - provincial and federal tax are calculated on the same basis as other elements - replacement price relative to gasoline.

- dollars per gigajoule (GJ) price - effectively the same as the replacement value price except prices are expressed in common energy units rather than volumetric units. The $/GJ price is corrected to account for efficiency improvements in using methanol. (i.e. methanol is 15 to 25 percent more efficient than gasoline as an energy basis)

The results show that the effective price of methanol fuel using the current taxing approach is virtually identical to gasoline up to 1985, rising to 111 percent of the forecast gasoline price in 1995. Using the replacement tax criteria or the $/GJ formula, methanol shows a small advantage through to 1990 and a 4 percent price disadvantage in 1995 relative to gasoline. Methanol's competitive position will be significantly improved if federal and provincial taxes are not applied. If such an incentive is offered, effective methanol prices would be 73 and 81 percent of gasoline in 1985 and 1995 respectively.

5.3.3 Pricing methanol blends

Methanol is a potentially valuable blending agent because of it high octane properties. A refiner will blend methanol only to the extent that there is an economic incentive to do so. While methanol is a potential source of low cost octane, its value is diminished by the reduced upgrade achieved in the value of butane in gasoline. Butane must be withheld from the fuel to counteract the high vapour pressures of the blend fuel. A refiner must weigh these and other factors to determine the value of methanol to the refinery. This value will vary by refinery.

TABLE 5.4

ALTERNATIVE METHANOL PRICING OPTIONS

	Methanol Retail Price			Gasoline Retail Price	% Methanol To Gasoline
	Without Tax	Tax	Total		
1982					
Actual pump price (¢/l)	20.89	5.85	26.74	42.4	63
Effective price (current tax) ¢/l	31.34	11.24	42.58	42.4	100
Effective price (replacement tax) ¢/l	31.34	8.78	40.12	42.4	94
$/GJ (after efficiency correction)	8.98	2.52	11.50	12.18	94
1985					
Actual pump price (¢/l)	21.65	6.07	27.72	44.0	63
Effective price (current tax) ¢/l	32.48	11.67	44.15	44.0	100
Effective price (replacement tax) ¢/l	32.48	9.11	41.59	44.0	94
$/GJ (after efficiency correction)	9.30	2.61	11.91	12.64	94
1990					
Actual pump price (¢/l)	22.63	6.34	28.97	44.0	66
Effective price (current tax) ¢/l	33.95	12.18	46.13	44.0	105
Effective price (replacement tax) ¢/l	33.95	9.51	43.46	44.0	98
$/GJ (after efficiency correction)	9.75	2.74	12.49	12.64	98
1995					
Actual pump price (¢/l)	23.91	6.65	30.56	44.0	69
Effective price (current tax) ¢/l	35.87	12.78	48.65	44.0	111
Effective price (replacement tax) ¢/l	35.87	9.98	45.85	44.0	104
$/GJ (after efficiency correction)	10.42	2.91	13.33	12.64	104

Establishing the methanol value is complicated by the number of factors which must be optimized. These factors include the refinery product slate, gasoline composition and value, volume and price of methanol to be blended, the type, volume and price of co-solvents required, butane price and the incremental cost of other octane enhancing options. Other octane enhancing options immediately available include increased catalytic reformer severity, adding high cost toluene, organometallic manganese compounds (MMT, for example, is used to produce unleaded gasoline). Traditionally, the most inexpensive method of boosting octane ratings has been the addition of lead compounds. The recently announced federal lead phase-down proposal may limit this option in the future.

While recognizing the complexity of establishing exact methanol values for particular refineries, a generalized assessment can be performed to establish an indifference value to the refiner. Several assumptions are required:

- total oxygenate levels will be 10 percent in 1982, 1985 and 15 percent in 1990 and 1995.
- the co-solvent is TBA (tertiary butanol) and its prices will remain constant in 1982 dollars at 35¢/l.
- methanol to co-solvent ratios will be 1:1 in 1982 (as are currently being tested), 2:1 in 1985 and 1990, and 3:1 in 1995.
- gasoline prices are those forecast earlier less 25 percent in federal and provincial taxes.
- butane market prices will remain constant in 1982 dollars at 18.7¢/l.
- incremental octane cost will remain constant in 1982 dollars at 0.25¢ per octane litre. The value selected is a midpoint for octane enhancement from increased reformer severity.

There are several steps to establish an indifference price of methanol for the refinery. The first is to calculate the value of the oxygenate (methanol and co-solvent mixture).

- calculate the octane credit provided by the oxygenate.
- calculate the butane added value lost by removing butane from the gasoline.
- calculate the octane debit from removing butane.
- establish the value of the oxygenate - calculated as the price of gasoline + oxygenate octane credit - butane value debit - butane octane debit.

An example of these calculations for the year 1982 is shown in Table 5.5. Having established the value of the oxygenate, the methanol component is readily calculated. For the 10 percent blend, 1:1 alcohol:co-solvent ratio assumed for 1982, this would be:

$$\text{Methanol value} = \frac{\text{Oxygenate value} - (\text{co-solvent price} \times \% \text{ co-solvent})}{\% \text{ methanol}}$$

$$= \frac{28.7 - (35 \times 0.5)}{0.5}$$

$$= 22.4¢/l$$

The value of the oxygenate and the indifference price for methanol to the refinery over the study period will be as follows:

	1982	1985	1990	1995
Value of Oxygenate (¢/l)	28.7	30.0	30.0	30.5
Value of Methanol (¢/l)	22.4	28.0	28.0	29.0

To the refiner, the indifference value would not provide a financial incentive to utilize methanol. The incentive would require either a price reduction or an octane shortfall of cheaper alternatives. To the methanol marketer, the refinery indifference value is useful to establish the extent to which methanol will be attractive. Depending on the analysis, the producer may use a different co-solvent, adjust the price of methanol or change the methanol:co-solvent ratio.

Based on the above analysis, the gross margin to the producer can be calculated. Deducting the production price of methanol from the refinery's indifference value yields the manufacturers gross margin. To provide incentive to the refinery, a further 10 percent of the methanol price is deducted as an added refinery margin.

	(¢/l)			
	1982	1985	1990	1995
Indifference Price	22.4	28.0	28.0	29.0
Manufacturing Price	13.1	13.7	14.6	15.6
Gross Margin	9.3	14.3	13.4	13.4
Refinery Added Margin	1.3	1.4	1.5	1.6
Balance:	8.0	12.9	11.9	11.8

TABLE 5.5

EXAMPLE CALCULATION OF METHANOL INDIFFERENCE VALUE TO REFINERIES

	1982
Methanol Octane Credit	
Oxygenate R + M/2	106
Gasoline R + M/2	88
Improvement/l	18
Octane Replacement Cost (¢/octane l)	0.25
Octane Credit (¢/l)(1)	4.5
Butane Value Debit	
Gasoline price (¢/l)(2)	31.8
Butane price (¢/l)	18.7
Butane added value (¢/l)	13.1
Butane backout/l methanol	0.53
Butane added value lost (¢/l)(3)	(6.9)
Butane Octane Debit	
Butane R + M/2	93
Gasoline R + M/2	88
Loss in Octane/l	5
Butane backout/l methanol	0.53
Lost Octane (R + M/2)	2.7
Octane Replacement Cost (¢/octane l)	0.25
Octane Debit (¢/l)(4)	(0.7)
Oxygenate Value: (2 + 1 - 3 - 4)	28.7

The balance must be sufficiently high to offset all transportation and marketing costs for both the refiner and the manufacturer. After these costs have been accounted for, the prices paid by the refinery could be increased (positive net balance) or decreased (negatve net balance).

In the early stages of methanol blend market penetration, these other costs could be high as modifications to the distribution infrastructure as undertaken (i.e. storage tanks, etc.) cost of performing test demonstrations are recovered and marketing costs are offset. At some point, these development costs would be part of the cost of doing business and would decrease in significance. At that point, the methanol manufacturer could increase prices or by offering a substantially lower price than the refinery indifference value, allow the refinery to choose between an increased refiner margin or lower consumer gasoline prices.

6. ALCOHOL FUEL MARKET POTENTIAL

Potential consumers will only consider purchasing alcohol fuels when all technical issues have been resolved and the institutional and regulatory approvals process has been completed. At this point, the commercial utilization prospects will be mostly a question of convenience and economics. Deriving the market potential for alcohol fuels requires:

- an appreciation of the size and characteristics of the vehicle market and the identification of that part of the total market which is best suited to alcohol fuels.
- estimating the timeframe within which the regulatory/institutional and technical preconditions will be established.
- determining their market penetration into the selected market segments based on alcohol fuel convenience and economics.

This chapter documents these considerations.

6.1 VEHICLE MARKETS

Vehicle markets are highly diverse, both in the type of vehicles and the ways in which they are used. All vehicle markets will not be ideal candidates for alcohol fuels. The nature of future alcohol fuel penetration and utilization will be influenced by the extent to which the fuel, engines and markets are matched. This section will present vehicle stock data for 1981 and forecasts to 1995, discuss the characteristics of the various market segments and identify target markets.

6.1.1 Market segments

Base year (1981)

Motor vehicle population estimates are summarized by Province in Table 6.1. Inconsistencies in the way in which vehicle registrations are collected across the country require several assumptions (supported by other studies) to be made to arrive at the estimates in Table 6.1

- light, medium and heavy trucks are on average, represented by 83%, 11% and 6% of total truck registrations respectively.
- of the total light truck registrations, 80% are personal use, 20% are for commercial applications.
- medium and heavy duty trucks are used for commercial activities only.

TABLE 6.1

1981 MOTOR VEHICLE INVENTORY
('000 vehicles)

	B.C.	Alberta	Sask.	Manitoba	Ontario	Quebec	N.B.	N.S.	TOTAL
Automobile	1,145.4	1,187.8	373.8	460.2	3,725.0	2,393.4	252.9	349.7	9,888.2
Light Truck (0-5,000 Kg)									
- Personal	307.6	325.2	165.1	130.2	564.2	306.8	69.0	98.1	1,966.2
- Commercial	76.9	81.3	41.2	32.5	141.1	76.7	17.3	24.5	491.5
Medium Truck (5,001-15,000 Kg)	21.4	66.6	73.6	18.6	85.9	45.5	5.8	8.3	325.7
Heavy Truck (15,001 + Kg)	21.2	16.6	14.9	3.7	68.8	36.4	4.9	6.9	173.4
Total:	1,572.5	1,677.5	668.6	645.2	4,585.0	2,858.8	349.9	487.5	12,845.0

Sources: Provincial Motor Vehicle Population Records.
Statistics Canada, Catalogue 53-219
Motor Vehicle Manufacturers Association, Facts and Figures, 1981

As indicated in the Table, automobiles and light duty trucks represent 92 percent of the total vehicle population, while commercial light, medium and heavy duty trucks represent only 4 percent, 3 percent and 1 percent respectively. Ontario and Quebec represent 58 percent of all vehicles, B.C. 12 percent, the prairie provinces 23 percent and New Brunswick and Nova Scotia 7 percent of all vehicles.

Vehicle population forecasts

Vehicle populations in the future will be a function of many inter-related variables, including population growth, household size, disposable income, consumer preferences, and economic conditions which influence production and shipping. Several specific assumptions have been made to forecast vehicle populations for each vehicle type. They are described below.

The average number of automobiles per capita in Canada increased substantially during the period 1970 to 1981, from 0.31 to 0.42 vehicles per capita. For the period 1982 to 1995 a more modest growth is forecast, from 0.42 to 0.47 vehicles per capita. Light duty trucks are forecast to increase at the same rate as automobiles. Over the study period, light duty trucks will increase from 0.10 vehicles/capita to 0.11 vehicles/capita. On average, these two vehicle categories will grow at a rate of 2 percent per year. Provincial rates will vary, depending on the level of saturation, historic growth rates and expectations of regional economic activity.

The growth rate of medium and heavy duty trucks will depend on the requirement to provide increased carrying capacity. This will in turn depend on the economic environment and any changes in modal distribution of freight shipments. Transport Canada has forecast an increase in for-hire trucking tonnage of 3.6 percent per year throughout the 1980's. This growth rate is assumed to be a reasonable proxy for the carrying capacity requirements of medium and heavy trucks.

Based on these considerations, national vehicle populations for each segment are forecast to 1995. As shown in Table 6.2, the total stock is forecast to increase by 4,051,900 vehicles, of which automobiles and light trucks account for 96 percent. The proportional distribution of the various vehicle types remains more or less constant over the study period. Disaggregating the national data to the provincial level shows no significant variation in the proportion of regional populations compared to the base year. Ontario, Quebec, New Brunswick and Nova Scotia will each account for slightly less of the total vehicle stock compared to the base year and British Columbia, and the prairie provinces slightly more.

6.1.2 Vehicle market characteristics

Automobiles

Passenger automobiles comprise 77 percent of the total vehicle population, ranging from 84 percent in Quebec, to 56 percent in Saskatchewan. As indicated

TABLE 6.2

MOTOR VEHICLE FORECASTS (1981 - 1995)
('000 vehicles)

	1981	1985	1990	1995
Automobile	9,888.2	10,899.4	11,962.3	12,998.5
Light truck	2,457.7	2,721.2	2,961.9	3,235.7
Medium truck	325.7	360.6	392.5	428.8
Heavy truck	173.4	196.7	214.1	233.9
Total:	12,845.0	14,177.9	15,530.8	16,896.9

Source: Derived from Canadian Resource Con limited, The Market Potential for CNG as a Motor Vehicle Fuel in Canada, December, 1982.

in the last section, the population of automobiles is forecast to grow by 3.1 million vehicles between 1981 and 1995.

As a national average, passenger automobiles are estimated to travel roughly 15,550 km per year, ranging from 13,500 km in British Columbia to 17,800 km in Nova Scotia. On average, 66 percent of all vehicles travel less than 18,250 km per year, while approximately 5 percent travel in excess of 36,500 km per year.

Annual fuel consumption of these vehicles will vary over the study period as vehicle fuel efficiency improves. Average new vehicle fuel efficiency is forecast to improve by 32 percent over the study period from 12.58 l/100 km in 1981 to 8.54 l/100 km in 1995. Most of this efficiency improvement is observed by 1985. As a result, average national fuel consumption will decline by 630 litres per vehicle per year by 1995, from 1,960 litres in 1981; 1,560 litres in 1985; 1,440 litres in 1990; and 1,330 litres in 1995. Regional variation by provinces can be expected due to varying climatic conditions and vehicle buying patterns.

Light trucks

The population of light trucks is forecast to grow by 778,000 vehicles between 1981 and 1995. Light trucks will represent roughly 19 percent of the total vehicle population throughout the period. As indicated earlier, roughly 80 percent of these vehicles are estimated to be used for personal applications, the balance for commercial purposes.

In the absence of data to suggest otherwise, average distance travelled is assumed to be the same as passenger automobiles, as is any variation from the average within the provinces. Average fuel consumption will be higher for these vehicles, as fuel efficiency is relatively poorer than with automobiles. Average new vehicle fuel efficiency is forecast to improve by roughly 27 percent over the study period, however, from 16.67 l/100 km in 1981 to 12.18 l/100 Km in 1995. Average fuel consumption will decline by 700 litres per vehicle per year by 1995; from 2,590 litres in 1981; 2,200 litres in 1985; 2,000 litres in 1990; and 1,890 litres in 1995.

Medium duty trucks

Medium duty truck populations are forecast to increase by 32 percent by 1995, or 103,100 vehicles. These vehicles will account for roughly 3 percent of the total vehicle stock throughout the study period.

On average, these vehicles are assumed to travel 16,430 km per year with fuel efficiencies of 40.0 l/100 km. Fuel efficiency improvements are anticipated to be more modest than for lighter vehicles. A 15 percent improvement is assumed by 1995. Annual fuel requirements per vehicle will, therefore, be roughly 5,600 liter in 1995 compared to 6,570 in 1981.

Heavy duty trucks

These vehicles are predominantly highway tractor-trailers but also include dump trucks, garbage trucks, etc. Only 1 percent of the total vehicle population are represented by these vehicle types. Although few in number, these vehicles individually consume more fuel energy than any other market sector. Average distances of 56,000 km per year and fuel efficiencies of 55.6 l/100 km yield a requirement for 31,100 litres of fuel per vehicle per year. Fuel efficiency improvements are also anticipated to be less pronounced than the lighter vehicle classes. A 15 percent improvement in fuel efficiency by 1995 will result in annual fuel requirements of 26,500 litres in that year.

6.1.3 Alcohol fuel target markets

The commercial attractiveness of methanol will vary by the type of fuel to be displaced (i.e. gasoline or diesel) and the required engine technology (i.e. spark ignition or compression ignition). Overall, vehicle markets which rely on gasoline spark ignition engines will be more ideal short to medium term candidates for methanol. This essentially limits the market to passenger automobiles and light duty trucks.

Substantial portions of the medium and heavy duty vehicle markets have already converted to diesel fuel. The heavy duty market has virtually reached saturation levels. Medium duty vehicles, although not as advanced in their conversion to diesel, have witnessed substantial penetration in the last decade. To the extent that compression ignition engines will dominate these two markets over the study period, methanol is unlikely to be as attractive a fuel as in spark ignition engines. As reviewed in Chapter 3, there is substantial interest within the research community on utilizing alcohols in compression ignition engines, but the state of technology development is not advanced. To achieve technical readiness will require a significant level of additional research, development and demonstration. The prospects are complicated by the number of technical options available. Many of these options have, to date, received scant attention in North America. The various alcohol options have not been matched to available engine technologies to establish their compatibility. To the extent that all the options are viable, there may be no one best way for all engine manufacturers. The various manufacturers may each select different options as most appropriate for their particular engine. This is in marked contrast to spark ignition engines where the requirements are clear and will be universally applicable among the manufacturers.

A simplifying occurrence which would make alcohols more attractive in this market would be the emergence of an alternative engine technology, such as the DISC. This engine would be broadly compatible to a number of fuels, whether gasoline, diesel or alcohol. Within the timeframe of this study, however, the DISC would have only marginal impact, even if it is assumed to be commercially available by the end of the decade.

The passenger automobile and light duty truck markets are more attractive than medium and heavy duty trucks. Diesel penetration into these markets has been modest and many observers believe it will not expand and may even contract. Diesel efficiency improvements are not as pronounced in these lighter vehicles and the narrowing price gap between gasoline and diesel make it more difficult to justify the cost increments required for a compression ignition engine. These vehicle markets also represent 96 percent of the vehicle population, compared to 4 percent for medium and heavy duty trucks. The opportunity for substantial penetration is more evident.

Spark ignition engines offer the advantage of utilizing alcohols as blended or neat fuels. Blends with gasoline will require no or only minor adjustment to the engine and fuelling system. At modest levels, they will be broadly compatible with vehicles already in-service. Neat alcohols will require engines and fuelling systems optimized to their use. This will require redesign and some materials replacement. The requirements are generally well understood and several vehicle manufacturers have already indicated an ability to produce such vehicles given the appropriate market signals.

6.2 MARKET PENETRATION

The introduction of methanol blends or neat methanol into national transportation markets will require the resolution of outstanding issues in technical readiness and regulatory and institutional compliance as discussed in chapters 3 and 4. The requirements for both fuel types are discussed in this section and an estimate made of the year in which each may be commercially available.

Having established the date of commercial availability, each fuel type is penetrated into the appropriate vehicle markets. There is only limited historical experience to guide the development of penetration rates for alternative fuels. For this study, two fuels are used as proxies to represent the penetration potential of methanol. For methanol blends, the experience of introducing unleaded gasoline into the national market is used. For neat methanol, the penetration of diesel fuel and compression ignition engines into the medium duty truck market is used. To provide a range of outcomes, two penetration scenarios are evaluated for blends and neat methanol, based on the observed penetration of the proxy fuels and engines.

6.2.1 Methanol blends

Commercial availability

With a concerted effort, methanol blends could be commercially available by 1985 for low level blends and 1990 or earlier for higher level blends. Pre-conditions to full scale penetration are discussed below.

Interim specifications which ensure consistent fuel quality within and among regions is required. For low level blends, few changes to existing gasoline

specifications will be required. Specific requirements will include defining volatility characteristics over a wide range of climatic conditions, co-solvent additions to minimize phase separation and ensuring there are no adverse, unanticipated impacts on refineries. Higher level blends have essentially the same requirements. In addition, anti-wear additives will require evaluation to counteract the propensity for wear related problems as the concentration of methanol in the blend is increased.

The physical distribution system requires evaluation to ensure no materials compatibility problems or conditions which may promote unacceptable phase separation. Marketing systems require evaluation in greater depth, particularly the location of blending activities. To the extent that the existing hydrocarbon fuel infrastructure can be used, penetration will occur more rapidly and easily than if distinct marketing systems must be established. Where refineries are used as a blending location, the compatibility of the methanol blend in product pipelines must be demonstrated. If methanol blends can be demonstrated as "fungible" commodities, market penetration will be greatly enhanced.

As the fuel blend will have generally similar specifications as gasoline, regulatory issues should not be a significant constraint. Firefighting techniques and equipment must be specified and made widely available. Allowance for marginally poorer fuel efficiency (on a volume basis) may be required.

Existing vehicles will be broadly compatible with alcohol blends. Confirmatory testing (as is now occurring) will be complementary with fuel specification research to ensure that no or at worst, acceptable loss in performance occurs. For higher level blends, engine materials compatibility must be demonstrated.

Methanol blend penetration

The characteristics of methanol blends will be the same as conventionally formulated unleaded gasoline. The consumer is likely to be indifferent in his choice of one over the other, assuming similar prices. In fact, the consumer need not even know methanol is used unless a marketing advantage can be gained. The penetration of unleaded gasoline into the transportation market is used to estimate the demand potential of methanol blends.

Since its introduction in 1975, unleaded gasoline has captured a rapidly increasing share of the gasoline market. As indicated in Table 6.3 market share increased from 6 percent in 1975 to 30 percent in 1981. This represents an average annual growth rate of 34 percent. During the same time period, total gasoline sales increased by 1.4 percent per year and premium and regular gasoline declined by 3.6 percent and 3.5 percent per year, respectively. Market share for unleaded gasoline is expected to increase further. Prior to the announced federal lead phase down proposal unleaded gasoline had been forecast to capture over 50 percent of the gasoline market by 1990. The lead phase down proposal may accelerate the trend and result in even higher market share.

TABLE 6.3

RETAIL PUMP SALES OF GASOLINE 1971 - 1981

	Premium		Regular		Unleaded		Total	
	Gl*	%	Gl	%	Gl	%	Gl	%
1971	8.32	30	18.96	70	-	-	27.28	100
1973	7.77	25	23.59	75	-	-	31.36	100
1975	4.91	14	26.96	80	1.95	6	33.82	100
1977	3.14	9	25.91	73	6.41	18	35.46	100
1979	4.27	11	24.59	65	9.00	24	37.86	100
1981	3.96	11	21.73	59	11.27	30	36.96	100

Gl = giga litre = 10^9 litres.

Source: Ethyl Canada, Inc.

Unleaded gasoline was introduced into the national market. Initial penetration was highest in Ontario and Quebec, representing 73 percent of sales in 1975. As indicated below, the other provinces have increased their relative share of sales, over the intervening years.

Regional Market Share of Unleaded Gasoline (%)

	1975	1981
Maritimes	8	10
Ontario and Quebec	73	65
Prairies	10	17
B.C.	7	8

Although the average annual growth rate of unleaded gasoline was 34 percent between 1975 and 1981, it was relatively more rapid in the initial years than in the latter years. Between 1975 and 1978, sales increased by 62 percent per year compared to 11 percent from 1978 to 1981.

As indicated earlier, methanol blends are assumed to be commercially available to national markets in 1985. As established in Chapter 5, methanol supply prices are well below the refinery indifference price, even after allowing for an increased refinery margin. On this basis, it is assumed that methanol blends with gasoline will be priced at the same level as conventional unleaded gasoline. In later years, it may be priced at a lower level, but this will depend on decisions taken by both the methanol producer and the refiner. Blend levels and methanol:co-solvent ratios are assumed to be 10 percent at 2:1 in 1985, 15 percent at 2:1 in 1990, and 15 percent at 3:1 in 1995.

To give a range of outcomes, two penetration rates are evaluated:

- High penetration - In this case, penetration of methanol blends proceeds at the same rate as that observed for unleaded gasoline. It represents an upper limit; the introduction of unleaded gasoline was mandatory, while methanol blends will require an economic rationale. This penetration rate does indicate, however, the capacity of the existing infrastructure to quickly introduce a "fungible" and substantially similar fuel into the transportation market. The assumptions used in this case are: in 1985, 1,950 Ml of methanol blend gasoline is sold; between 1985 and 1989, penetration proceeds at an average annual rate of 62 percent; and between 1989 and 1995, penetration slows to 11 percent per year.

- Low penetration - In this case, penetration occurs at half the observed rate of unleaded gasoline. In 1985, 980 Ml of methanol blend gasoline is sold. Between 1985 and 1989, penetration proceeds at an average rate of 31 percent per year. Between 1989 and 1995, penetration slows to 6 percent per year.

Using these assumptions, the volume of methanol blend gasoline is forecast through the study period. The volume of methanol and co-solvent required to satisfy the assumed blend levels are calculated and compared to their availability. The number of vehicles utilizing the blends is estimated. The results are shown in Table 6.4.

Methanol demand will exceed the 1.5 million tonnes (1900 Ml) per year production capacity surplus to existing domestic markets, in the scenario which parallels the introduction of unleaded gasoline. Demand increases from 7 percent of the surplus capacity in 1985 to 125 percent in 1995. In the lower penetration scenario, demand in 1995 is 31 percent of available methanol supplies.

Co-solvent availability will be a limiting factor regardless of the assumed penetration rate. Total available supplies from all domestic sources is estimated to be 87,000 tonnes (110 Ml) per year. Under high penetration assumptions, co-solvent demand exceeds availability by 680 percent in 1990 and 720 percent in 1995. For the low penetration case, demand exceeds supply by 136 percent in 1990 and 173 percent in 1995. There are several response options available to the industry to offset the projected short fall in co-solvent availability. In the short term, TBA may be imported from the United States. The extent to which TBA is available in sufficient quantities to meet the projected demand requires verification. Over the longer term, additional domestic production appears justified. Two response options are possible. Methanol manufacturers could retrofit existing facilities to produce methyl fuel. Alternatively, dedicated co-solvent production facilities could be established. The economic benefits of these two supply options requires clarification.

The forecast of blend sales, in combination with average annual vehicle fuel requirements and the vehicle population forecasts discussed earlier, allow an estimate of the number of vehicles using methanol blends to be made. For the high penetration scenario, 92 percent of gasoline powered vehicles are forecast to use methanol blends in 1995. For the low penetration scenario, roughly 22 percent of vehicles will utilize methanol blends in 1995.

6.2.2 Neat methanol

Commercial Availability

Neat methanol will require a more substantial level of effort than methanol blends to achieve widespread introduction into vehicle markets. It is unlikely to be commercially available to national markets before 1990.

Specific testing procedures to establish specifications require development. Procedures to establish seasonal volatility adjustment, evaporative emission control and vapour lock protection requires further definition. Additive packages for flame colourants, and anti-corrosion and anti-wear treatments are still under development. Specifications related research must be geared to the varying seasonal climatic conditions encountered across the nation.

TABLE 6.4

PENETRATION OF METHANOL BLENDS (1985 - 1995)

	Scenario 1			Scenario 2		
	1985	1990	1995	1985	1990	1995
Assumptions						
Blend sales (Ml)	1,950	14,910	21,120	980	3,060	5,160
Oxygenate level (%)	10	15	15	10	15	15
Methanol:Co-solvent	2:1	2:1	3:1	2:1	2:1	3:1
Methanol avail. (Ml)	1,900	1,900	1,900	1,900	1,900	1,900
Domestic co-solvent availability (Ml)	110	110	110	110	110	110
Results						
Methanol demand (Ml)	130	1,490	2,375	65	305	580
% of availability	7	78	125	3	16	31
Co-solvent demand (Ml)	65	745	792	30	150	190
% of availability	59	680	720	27	136	173
No. of vehicles ('000)	1,164	9,600	14,646	585	1,970	3,578
% of population	9	65	92	4	13	22

Distribution and marketing systems for neat methanol must be established. To keep distribution costs to a minimum, the existing hydrocarbon infrastructure should be used to the greatest extent possible. Materials compatibility must be demonstrated for the transport of neat methanol from Western producers by clean products pipeline. Marketing channels must be established which minimize handling and interim storage requirements and the potential for degradation in product quality.

The regulatory environment faced by neat methanol requires careful review to ensure that there are no outstanding issues by 1990. Several individuals interviewed from various regulatory agencies expressed the view that little interest would be shown until methanol became a commercial option. To delay the resolution of regulatory issues until all other technical and economic concerns have been resolved, could needlessly delay widespread introduction of methanol by several years. In addition to establishing specifications, several other areas require attention. These include:

- establishing vehicle safety with respect to fuels containment.

- establishing emissions compliance. Although emissions are expected to be better than gasoline with the exception of aldehydes, testing procedures must be established. To the extent that emissions compliance tests may be a specific regulatory problem in the U.S. due to their particular situation, reliance on U.S. standards may not be a feasible approach.

- fuel handling and firefighting requirements must be widely circulated.

- taxation policy should be reviewed to determine the best method by which methanol's disadvantageous lower energy density but advantageous higher fuel energy efficiency may be treated for taxation purposes.

Developing the requisite engine technology for neat methanol should not be a limiting factor, but it will take time to select, test and optimize all the variables in the engine/vehicle configuration. These activities are best performed in concert with the fuels specifications development. Broad agreement is required between the fuels and automotive industries. The latter is unlikely to offer warranties until there is a sure knowledge of the fuel's parameters within which the vehicle must operate and confidence that standards will be universally applied within the tolerance of the engine system. Extensive and potentially time-consuming pre-market testing is likely.

Neat Methanol Penetration

As indicated above, neat methanol is assumed to be commercially available to national markets in 1990. The historical rate of diesel vehicle sales in the medium duty truck market is used to estimate neat methanol's penetration into the passenger automobile and light duty truck gasoline market. Diesel and methanol are both substantially different fuels than gasoline and both require engines optimized to their use. As factory optimized vehicles are required, penetration is restricted to a portion of new vehicle sales. Historical diesel sales are used as a proxy to establish that portion of the new vehicle market which are likely neat methanol conversion opportunities. Several assumptions are made.

- new vehicles will be about 14 percent of the vehicle population in any given year. This corresponds to an average vehicle life of 7 years.

- the observed rate of diesel penetration is adjusted to reflect any methanol price advantage over gasoline relative to the historical diesel price advantage. The effective diesel fuel price was on average 28 percent lower than gasoline in the early stages of it's penetration, for example. Where the methanol price advantage is higher or lower than this diesel advantage, methanol penetration will proceed faster or slower.

- where there is no price advantage relative to gasoline, no penetration will occur.

Two penetration scenarios, based on different pricing assumptions are evaluated. The affect of government taxation policy on penetration is assessed for each scenario: in one case, methanol penetration proceeds on its own economic merits with no incentives; in a second case, methanol penetration is encouraged by not assessing any federal or provincial fuel taxes.

- Base Case Scenario - methanol penetration proceeds based on the effective utilization prices of neat methanol relative to gasoline as derived in Chapter 5 and summarized in Table 5.4 This scenario is based on no real price increases in crude oil over the study period.

- Alternate Scenario - in this scenario, an annual 2 percent real growth rate in crude oil prices is assumed from 1985 to 1995. Methanol prices are held to the same level as in the base case to reflect continuing soft export market prices or volume price discounting to the transportation market. Based on the relationships between crude oil, natural gas and methanol production prices, the effective discount by producers will be about 1.75 ¢/l in 1990 and 3.02 ¢/l in 1995.

The methanol and gasoline pricing assumptions for both scenarios is shown in Table 6.5. Also shown is the methanol price advantage over gasoline, with and without taxes, and the payback period on an assumed $250 incremental methanol vehicle cost. Under the base case scenario methanol is unlikely to be competitive on its own merits. Where federal and provincial fuel taxes are not assessed, methanol will have a 23 percent price advantage over gasoline in 1990 and 18 percent in 1995. For the alternate scenario, methanol will have a price advantage over gasoline for both taxation cases: an average of 10 percent from 1990 to 1995 in the full taxation case; and 30 percent where fuel taxes are not assessed.

In the early years the proportion of new vehicle sales optimized for a completely different fuel is small in relation to total sales. As consumers become more familiar and confident with the new fuel and vehicle technology and as it's availability expands, penetration becomes more rapid. The timeframe for this study allows only 6 years of methanol penetration between 1990 and 1995. Over the first 6 years of diesel sales, normalized penetration varied between 1.2 percent of new vehicle sales in the initial year to 6.6 percent in year six.

The price spreads between gasoline and methanol discussed above suggest that:

- base case penetration will vary between 63 and 75 percent of the observed penetration of diesel for the no tax case and no penetration will occur for the full tax case.

- alternate scenario penetration will be about 38 percent of the diesel rate for the full tax case but 113 percent where no fuel taxes are assessed.

Applying the expected penetration rates against the forecast new vehicles sales (14 percent of automobile and light truck populations from Table 6.2) yields the number of annual neat methanol vehicle sales over the period 1990-1995. The results are shown in Table 6.6 for the years 1990 and 1995 and cummulative totals for the 6-year penetration period. Where penetration occurs, neat methanol vehicles will account for 1.2 percent to 3.6 percent of the total automobile and light truck vehicle population in 1995, depending on the scenario.

	% of target population 1995
Base Case Scenario	
With tax	0.0
Without tax	1.8
Alternate Scenario	
With tax	1.2
Without tax	3.6

TABLE 6.5

NEAT METHANOL AND GASOLINE
PRICING ASSUMPTION (1982 DOLLARS)

Base Case Scenario	1990	1995
Base Case Scenario		
With Taxes		
Methanol Price (¢/l)	43.5	45.9
Gasoline Price (¢/l)	44.0	44.0
% Methanol to Gasoline	99	104
Payback Period (years)	-	-
Without Taxes		
Methanol Price (¢/l)	34.0	35.9
Gasoline Price (¢/l)	44.0	44.0
% Methanol to Gasoline	77	82
Payback Period (years)	1.7	2.3
Alternate Scenario		
With Taxes		
Methanol Price (¢/l)	43.5	45.9
Gasoline Price (¢/l)	47.7	51.7
% Methanol to Gasoline	91	89
Payback Period (years)	4.0	3.25
Without Taxes		
Methanol Price (¢/l)	34.0	35.9
Gasoline Price (¢/l)	47.7	51.7
% Methanol to Gasoline	71	69
Payback Period (years)	1.3	1.2

TABLE 6.6

NEAT METHANOL VEHICLE FORECAST

	Annual Sales		In Service
	1990	1995	1995
Base Case Scenario			
With Taxes	--	--	--
Without Taxes	18,800	74,960	296,540
Alternate Scenario			
With Taxes	9,410	56,330	194,830
Without Taxes	28,200	168,770	584,250

Annual methanol demand for these vehicles is readily calculated by applying the annual vehicle fuel requirements derived in section 6.1.2 and correcting for methanol fuel content (90 percent) and energy content and efficiency (150 percent). The results are shown in Table 6.7. Under the no fuel tax base case scenario for 1995, methanol demand will be 577.1 Ml or 30.4 percent of the 1,900 Ml of current available capacity not required for domestic industrial markets. For the alternate scenario, price discounting by producers, in combination with rising gasoline prices yields a methanol demand of 379.2 Ml in 1995 with fuel taxes applied. If further incentives are available by not applying fuel taxes, methanol demand would be 1.137.0 Ml. These levels of demand are 20.0 percent and 59.8 percent of available capacity, respectively.

TABLE 6.7

NEAT METHANOL DEMAND FORECAST

	METHANOL DEMAND			
	1990		1995	
	With Tax (Ml)	Without Tax (Ml)	With Tax (Ml)	Without Tax (Ml)
Base Case Scenario				
Automobile	-	21.7	-	315.9
Light Truck	-	7.5	-	111.5
Total:	-	29.2	-	427.4
Volume Correction (0.9)	-	26.3	-	384.7
Efficiency Correction (1.5)	-	39.4	-	577.1
% Available Capacity	-	2.1	-	30.4
Alternate Scenario				
Automobile	10.9	32.5	207.6	622.4
Light Truck	3.7	11.2	73.3	219.8
Total:	14.6	43.7	280.9	842.2
Volume Correction (0.9)	13.1	39.3	252.8	758.0
Efficiency Correction (1.5)	19.7	59.0	379.2	1137.0
% Available Capacity	1.0	3.1	20.0	59.8

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